



MATS
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MATS CENTRE FOR DISTANCE & ONLINE EDUCATION

Diversity of Seed Plants & their Systematics

**Bachelor of Science (B.Sc.)
Semester - 3**



SELF LEARNING MATERIAL



DSCC 301
Diversity of seed plant and
their systematics
CODE: ODL/MSS/BSCB/301

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MODULE INTRODUCTION

Course has five modules. Under this theme we have covered the following topics:

MODULE 01: Introduction to seed plant

MODULE 02: Gymnosperm

MODULE 03: Angiosperm

MODULE 04: Classification of angiosperm

MODULE 05: Diversity of flowering plant

These themes of the Book discuss about Seed plants (spermatophytes) exhibit remarkable diversity, encompassing gymnosperms (naked seeds) and angiosperms (flowering plants), with systematics focusing on their classification and evolutionary relationships. This book is designed to help you think about the topic of the particular module. We suggest you do all the activities in the modules, even those which you find relatively easy. This will reinforce your earlier learning.



MODULE -1

INTRODUCTION TO SEED PLANTS

1.0 Objectives

- Understand the characteristics and classification of seed plants.
- Explain the evolution of the seed habit in plants.
- Differentiate between fossil and living seed plants.
- Explore gymnosperms, their classification, and their evolutionary diversity.
- Learn about the geological time scale and its significance in plant evolution.
- Understand fossilization, fossil dating methods, and fossil gymnosperms.

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UNIT 1.1

Characteristics of seed plants

1.1.1 Introduction: Seed plants constitute one of the most successful evolutionary innovations in terrestrial life history. The seed, with its protective structures and ability to remain dormant during unfavorable conditions, has revolutionized reproduction in the plant kingdom, enabling a new era of plant life.

1. Production of Seeds

The most defining feature of seed plants is the production of **seeds**. Unlike ferns and other spore-bearing plants, seed plants retain the megaspore within the megasporangium (nucellus), where it develops into a female gametophyte. After fertilization, the zygote develops into an embryo, which, together with nutritive tissue and a protective seed coat, forms the seed.

2. Presence of Vascular Tissues

Seed plants have well-developed **vascular tissues**, namely xylem and phloem. Xylem (including tracheids, and in angiosperms, vessels) conducts water and minerals from the roots to aerial parts, while phloem distributes food produced in leaves to other organs.

3. Dominant Sporophyte Generation

In the life cycle of seed plants, the **sporophyte** (diploid) phase is dominant and long-lived, while the gametophyte (haploid) phase is highly reduced and dependent on the sporophyte. The male



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gametophyte is represented by the pollen grain, and the female gametophyte develops within the ovule.

4. Heterospory and Separate Male and Female Structures

Seed plants are **heterosporous**, producing two distinct types of spores: microspores (develop into male gametophytes) and megaspores (develop into female gametophytes). These spores are produced in separate structures microsporangia and megasporangia often arranged in cones (in gymnosperms) or flowers (in angiosperms).

5. Pollen and Pollination

The male gametophyte is released as a **pollen grain**, which is resistant to desiccation and can be transported by wind, insects, birds, or other agents to the female structure. This process, known as **pollination**, eliminates the dependence on water for fertilization, a major advancement over lower plants. Pollen germinates on the receptive surface and forms a **pollen tube** that delivers sperm directly to the egg.

6. Diversity of Habits and Forms

Seed plants show remarkable diversity in form and habitat. They range from towering trees like pines and oaks to tiny herbs like grasses. Their roots, stems, and leaves are often modified to adapt to specific environments—such as thick cuticles and needle-like leaves in conifers for dry conditions, or broad leaves in rainforest species to capture maximum sunlight.

7. Reproductive Structures and Fruits

In angiosperms, seeds are enclosed within an **ovary** that matures into a **fruit**, aiding in protection and dispersal. Gymnosperms, on the other hand, bear naked seeds on scales or leaves without such enclosure. Flowers, unique to angiosperms, have evolved various forms and colors

to attract specific pollinators, increasing reproductive efficiency

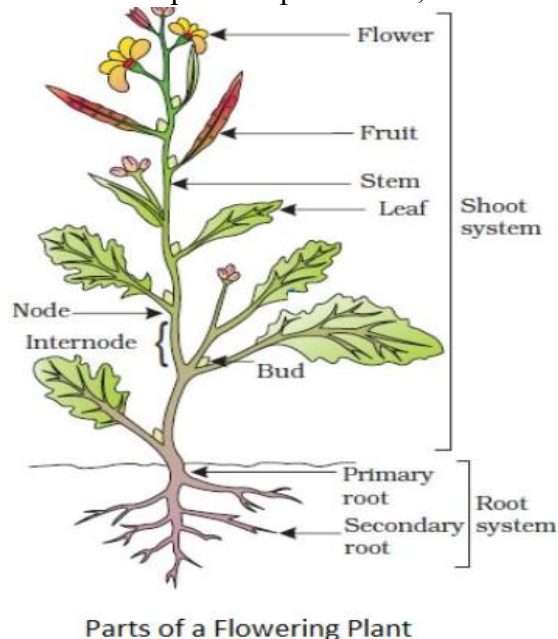


Fig. 1.1.External morphology of seed plant

1.1.2 Classification of Seed Plants

Seed plants, also known as **Spermatophytes**, represent the most advanced group of plants in the plant kingdom. They are characterized by the production of seeds, a feature that has allowed them to dominate terrestrial habitats. Unlike lower vascular plants that reproduce through spores, seed plants have developed ovules that, after fertilization, develop into seeds. These seeds are well protected, often supplied with stored food, and capable of remaining dormant until favorable conditions arise. On the basis of structural and reproductive features, seed plants are broadly divided into two major groups: **Gymnosperms** and **Angiosperms**.

1. Gymnosperms – Naked Seed Plants

Gymnosperms are the more primitive of the two groups and are often referred to as “naked seed plants” because their seeds are not enclosed within a fruit. The ovules are borne exposed on the surface of modified leaves called **megasporophylls**, which are usually arranged in structures like cones or strobili. Gymnosperms first appeared in the Paleozoic era and were dominant during the Mesozoic, often called the “Age of Cycads.” They are mostly perennial, woody plants such as trees and shrubs. Common examples include **Cycas**, **Pinus**, and **Ginkgo**.



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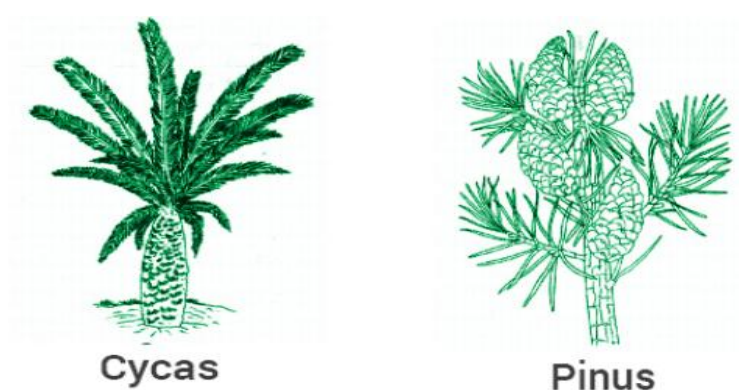


Fig. 1.2 External morphology of gymnosperm

2. Angiosperms – Enclosed Seed Plants (Flowering Plants)

Angiosperms are the most advanced and diverse group of seed plants, commonly referred to as **flowering plants**. They are characterized by the presence of flowers, which are specialized structures for reproduction. The ovules in angiosperms are enclosed within an ovary; after fertilization, the ovary matures into a **fruit** that protects the seeds and aids in their dispersal. Angiosperms show double fertilization, a unique feature in which one male gamete fuses with the egg to form a zygote, while the other fuses with two polar nuclei to form the endosperm that nourishes the embryo. This group dominates most ecosystems today, ranging from minute herbs to towering trees. Examples include **rice, wheat, mango, rose, and sunflower**.

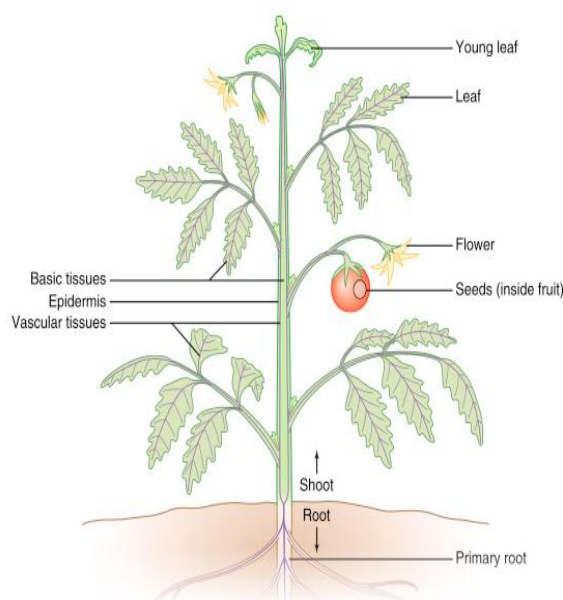


Fig. 1.3 External morphology of angiosperm

Major Divisions within Angiosperms



Angiosperms are further classified based on the number of seed leaves (cotyledons) present in the embryo and other morphological characters. They are divided into two large classes:

- **Dicotyledons (Dicots):** Seeds with two cotyledons, net-veined leaves, and vascular bundles arranged in a ring. Most trees, shrubs, and many herbs belong here (e.g., mango, pea, sunflower).
- **Monocotyledons (Monocots):** Seeds with a single cotyledon, parallel-veined leaves, and scattered vascular bundles. Most grasses and palms belong here (e.g., rice, maize, wheat, coconut).

1.1.3 Evolution of the Seed Habit

Seed evolution is one of the most important innovations in plant evolutionary history, transforming the strategies of plant reproduction and dispersal. The seed habit wasn't some discontinuous jump, but rather the outcome of millions of years of gradual evolutionary modifications in the Late Devonian and Early Carboniferous, between 385 and 320 million years ago. The basis of these seeds is seen in the reproductive structures of progymnosperms, an extinct group of free-sporing woody plants that have vascular tissue with secondary growth, like modern seed plants. A key development en route to seed evolution was the transition from homospory (the production of one type of spore) to heterospory (the production of distinct male and female spores). Heterospory opened the door to reproductive division of labor: small male spores (microspores) for fertilization, larger female spores (megaspores) with greater stockpiles of resources to nurture an embryo. The next big step in evolution was keeping the megaspore inside the parent sporangium (the spore-producing structure instead of being released (the next evolutionary step). The retention kept the female gametophyte in close proximity to the and can be even be nourished by the parent plant, providing a safe environment for embryo development. At the same time, the development of integuments — protective coverings around the megasporangium — led to the creation of the ovule, the precursor of the seed. Some of the first well-established seed plants are Late Devonian elements, such as *Elkinsia* and *Archaeosperma*. These earliest seeds were quite basic, as compared to modern forms, but nonetheless contained all major parts: a structure producing the embryo (nucellus), two protective integuments, and a micropyle (an opening, and the entry point for pollen in the seed). Although there have been many modifications in different lineages, this simple organizational pattern has been conserved throughout the evolution of the seed plants.



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Pollen evolved, too, in an equally revolutionary way. In contrast to the free-swimming sperm of the non-seed plants, which needed water in order to fertilize, pollen grains could be windborne or (later), animal-borne. The pollen tube, which sprouts from the pollen grain to transport the sperm cells to the egg, evolved as an adaptation for water-independent fertilization. This adaptation conferred several advantages in dry environments, making it possible for seed plants to infiltrate habitats that their spore-bearing antecedents could not occupy. During the Carboniferous and Permian (359–252 million years ago), the diversity of seed plants exploded, with lineages of seed ferns, cordaites, and early conifers all evolving. These plants evolved distinct mechanisms for capturing pollen, protecting seeds, and dispersing their offspring, depending on their ecological niche. Seed species diversity was notably impacted by the end-Permian mass extinction (circa 252 million years ago), although various lineages persisted and diversified throughout the Mesozoic Era. The Mesozoic Era (252–66 million years ago) witnessed the dominance of extant gymnosperm lineages, including cycads, ginkgoes, and conifers, and the origin, and rapid diversification of angiosperms. In flowering plants angiosperms the evolution of the flower brought together several of these reproductive innovations: carpels protecting the ovules, stamens releasing pollen and often brightly colored, fragrant petals that lure animal pollinators. The co-evolution of commensality, whereby angiosperms reciprocally interacted with one or more pollinators and seed dispersers, has been touted as a cause of rapid diversification and ecological dominance. Angiosperms gave rise to fruits, which facilitated the protection and dispersal of seeds. Fruit comes in a staggering range of forms, from fleshy berries alluring to animal dispersers to arid, windborne devices like the samara of a maple tree or the pappus of a dandelion. Over this evolutionary time, the seed habit has evolved and been adapted in various ways such that a wide variety of reproductive strategies is now observed among modern seed plants. The variations on the basic seed theme, from the massive, animal-dispersed seeds of coconut palms to the dust-like, wind-dispersed seeds of orchids, from fire-adapted cones of some pines to water-dispersed fruits of mangroves, reflect adaptations to the vast majority of the terrestrial environments on Earth.

1.1.4 Fossil and Living Seed Plants

Seed plants, or **Spermatophytes**, include both extinct forms known only from fossils and living groups that dominate the present vegetation. The history of seed plants reveals a long evolutionary journey from primitive ancestors to the highly specialized forms of today. Their study is important because fossil seed plants provide clues about how reproductive structures, leaf forms, and ecological adaptations evolved over millions of years.



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1. Fossil Seed Plants

The earliest evidence of seed plants comes from the late Devonian and Carboniferous periods, over 350 million years ago. Among these, the most significant group is the **Pteridosperms**, commonly called **seed ferns**. They looked like ferns with large fronds, but instead of reproducing by spores, they bore seeds on their leaves. Pteridosperms were widespread during the Paleozoic era and are considered a transitional link between spore-bearing ferns and modern seed plants.

Another important fossil group is the **Cycadophytes**, which include ancient cycads and Bennettitales. These plants flourished during the Mesozoic era, often called the “Age of Cycads,” and many had palm-like appearances. Fossils of **Glossopteris** from the Gondwana regions also show evidence of seed-bearing structures. Over time, these fossil seed plants declined and gave way to more advanced gymnosperms and, later, angiosperms.

2. Living Seed Plants (Gymnosperms and Angiosperms)

Among living seed plants, two major groups survive today: **gymnosperms** and **angiosperms**. Gymnosperms are the more ancient group, with seeds exposed on the surface of cone scales rather than enclosed in fruits. Living examples include **cycads**, **Ginkgo biloba** (a living fossil), **conifers** such as pines and firs, and **gnetophytes** like Ephedra. They are mostly woody plants adapted to diverse climates and often evergreen, playing a critical role in forests, especially in colder regions.

Angiosperms, or **flowering plants**, are the most diverse and ecologically dominant seed plants of the modern era. Their seeds are enclosed within fruits, and they possess flowers that attract pollinators, leading to efficient fertilization and dispersal. Angiosperms range from tiny herbs to giant trees, forming the basis of most terrestrial ecosystems and supplying food, timber, medicine, and countless other resources.

3. Significance of Fossil and Living Seed Plants

The fossil record of seed plants shows how evolutionary innovations—such as the retention of the megaspore, development of integuments, and eventual formation of seeds—allowed plants to thrive on land. Fossil seed plants bridge the gap between primitive vascular plants and the gymnosperms and angiosperms we see today. Living seed plants, on the other hand, represent the culmination of this evolutionary progress, with advanced reproductive strategies, structural diversity, and adaptability that ensure their survival in nearly every habitat on Earth.



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1.1.5 Seed Plant Structural and Functional Adaptations

1. Structural Adaptations in Seed Plants

Seed plants (Spermatophytes) have developed a range of **structural adaptations** that allow them to survive, grow, and reproduce successfully on land. These adaptations are primarily seen in their vegetative and reproductive organs and are closely linked to their ability to conserve water, capture sunlight, and protect their reproductive structures.

Roots – Anchorage and Absorption

Seed plants possess a **well-developed root system** that firmly anchors them in the soil. Tap roots and fibrous roots penetrate deep or spread widely, enabling efficient absorption of water and minerals even from deeper soil layers. In many species, roots are modified into storage roots (carrot, radish) or prop roots (banyan) to provide additional support and resources. The root cap and root hairs are structural modifications that protect the growing tip and increase surface area for absorption.

Stems – Support and Conduction

The stem is structurally adapted to provide mechanical support for leaves, flowers, and fruits. It contains a highly organized **vascular system** (xylem and phloem) for efficient conduction of water, minerals, and food. In many gymnosperms and dicotyledonous angiosperms, stems undergo **secondary growth**, forming wood and bark that add strength and longevity. Certain stem modifications also aid survival: rhizomes (ginger), bulbs (onion), and tubers (potato) store food, while tendrils (grapevine) help in climbing.

Leaves – Photosynthesis and Water Conservation

Leaves in seed plants show adaptations to optimize photosynthesis while minimizing water loss. Most leaves are flattened with a broad surface to capture sunlight, but in dry habitats, they may be modified into spines (cactus) or scales to reduce transpiration. The presence of a **cuticle** on the leaf surface and adjustable **stomata** allows the plant to regulate gas exchange while conserving moisture. In conifers, leaves are needle-shaped with sunken stomata, another structural adaptation to withstand harsh conditions.

Reproductive Structures – Ovules, Seeds, and Flowers

The most important structural adaptation of seed plants lies in their reproductive organs. Instead of producing exposed spores, they form **ovules enclosed by integuments**, which after fertilization develop into



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seeds. This structural innovation protects the developing embryo from desiccation and injury. In angiosperms, ovules are further enclosed within an ovary that matures into a **fruit**, providing an additional layer of protection and aiding in seed dispersal. The formation of flowers, with specialized sepals, petals, stamens, and carpels, represents an advanced adaptation that attracts pollinators and increases reproductive success.

2.Functional Adaptations in Seed Plants

Seed plants (Spermatophytes) are not only structurally advanced but also show remarkable **functional adaptations** that allow them to reproduce efficiently, survive environmental stress, and colonize a wide range of habitats. These adaptations relate to how their organs and tissues work together to ensure survival and reproductive success in terrestrial ecosystems.

Independence from Water for Fertilization

One of the most significant functional adaptations is the complete **elimination of the need for external water in fertilization**. In lower plants, male gametes (sperms) must swim through a water film to reach the egg, which restricts them to moist environments. Seed plants overcame this limitation by developing **pollen grains**. The male gametophyte is enclosed within a resistant wall and carried to the ovule by wind, insects, or other agents. Once it reaches the ovule, the pollen produces a **pollen tube**, delivering sperm directly to the egg without reliance on free water.

Seed Formation and Dormancy

After fertilization, the zygote develops into an **embryo** within a seed. The seed contains nutritive tissue (endosperm or female gametophyte) and is protected by a seed coat. A key functional adaptation is the ability of seeds to enter a state of **dormancy**, during which metabolic activity is minimal. This allows seeds to survive unfavorable conditions (drought, cold, fire) for months or even years, germinating only when environmental conditions become favorable.

Efficient Resource Use and Long-Term Survival

Seed plants have evolved efficient functional systems for resource transport and storage. Their **vascular tissues** (xylem and phloem) ensure rapid movement of water, minerals, and food between roots, stems, and leaves. Many seed plants also store surplus food in roots, stems, or seeds, which supports regrowth after dormancy or adverse seasons. The ability to produce **secondary growth** (wood and bark) provides not only structural strength but also functional longevity, allowing them to live for hundreds or even thousands of years.



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1.1.6 Significance of Seed Plants in Economy and Ecology

Seed plants, or **Spermatophytes**, are the backbone of terrestrial ecosystems and human civilization. Their ability to produce seeds has enabled them to spread widely and provide countless benefits to both nature and society. Their significance can be viewed from two perspectives: their **economic value** to humans and their **ecological roles** in sustaining life on Earth.

1. Economic Significance of Seed Plants

Seed plants supply the majority of the world's **food**, including cereals like rice, wheat, and maize, as well as pulses, fruits, and vegetables. These angiosperms feed not only humans but also livestock, forming the foundation of agriculture. Many seed plants such as **cotton, jute, and flax** provide fibers for textiles, while **timber trees** like teak, sal, and pine supply wood for construction, furniture, and paper industries.

They are also a rich source of **medicinal compounds** for example, *Rauvolfia serpentina* (source of reserpine), *Taxus baccata* (source of taxol), and *Cinchona* (source of quinine). Ornamental seed plants like roses, orchids, and lilies contribute to the floriculture industry. Oil-yielding plants such as mustard, sunflower, and coconut form the basis of edible oils, soaps, and cosmetics. Additionally, seed plants like rubber (from *Hevea brasiliensis*) and resins, gums, and tannins from various trees play vital roles in industries. In short, seed plants drive agriculture, forestry, pharmaceuticals, and numerous other sectors.

2. Ecological Significance of Seed Plants

Seed plants are also indispensable to the **balance of ecosystems**. Through photosynthesis, they release oxygen and absorb carbon dioxide, playing a central role in maintaining atmospheric gases. Their extensive root systems hold soil in place, preventing erosion, while forest canopies regulate local climates, reduce temperature extremes, and influence rainfall patterns.

Seed plants form the primary producers at the base of most terrestrial food chains, providing food and habitat for insects, birds, mammals, and countless other organisms. They also maintain biodiversity by offering niches for countless life forms. In addition, many seed plants engage in **mutualistic relationships** for example, flowering plants attract pollinators like bees and birds, supporting entire pollination networks essential for ecosystem health.



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Summary:

Seed plants, also called spermatophytes, are the most advanced and successful group of plants. Their chief characteristic is the formation of seeds, which protect and nourish the embryo and help in survival and dispersal. They are heterosporous, producing microspores that develop into pollen grains (male gametophytes) and megaspores that form the female gametophyte inside the ovule. Fertilization takes place through pollen grains and pollen tubes, so water is not required for reproduction. The ovule develops into a seed after fertilization, which may remain naked as in gymnosperms or enclosed within fruits as in angiosperms. The sporophyte is the dominant, independent generation, while the gametophyte is highly reduced and dependent. Seed plants possess a well-developed vascular system consisting of xylem and phloem for conduction of water and food. With features like pollen grains, seeds, vascular tissue, and protective adaptations, seed plants are highly suited to life on land and are classified into gymnosperms and angiosperms.

Multiple Choice Question (MCQs)

1. The most distinguishing feature of seed plants is:

- a) Flowers
- b) Presence of seed
- c) Vascular tissue
- d) Spores

Ans: b) Presence of seed

2. In seed plants, the male gametophyte is represented by:

- a) Anther
- b) Pollen grain
- c) Ovule
- d) Archegonium

Ans: b) Pollen grain

3. Which of the following is an adaptation of seed plants for life on land?

- a) Dependence on water for fertilization
- b) Pollen tube formation
- c) Flagellated sperms



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d) Lack of vascular tissue

Ans: b) Pollen tube formation

4. Gymnosperms differ from angiosperms in having:

a) Seeds without fruit covering

b) Double fertilization

c) Flowers

d) Vessels in xylem

Ans: a) Seeds without fruit covering

5. In seed plants, the gametophyte is:

a) Independent and free-living

b) Dominant

c) Reduced and dependent on sporophyte

d) Absent

Ans: c) Reduced and dependent on sporophyte

Short Answer Questions

1. Define spermatophytes.
2. Give two main differences between gymnosperms and angiosperms.
3. What is the role of pollen grain in seed plants?
4. Why are seed plants considered the most successful group of plants?
5. Write two advantages of seed over spore.
6. Mention two key features that distinguish seed plants from pteridophytes.

Long Answer Questions

1. Describe the major characteristics of seed plants with examples.
2. Explain how seeds are an evolutionary advantage over spores.
3. Discuss the adaptations of seed plants for life on land.

4. Compare gymnosperms and angiosperms on the basis of their reproductive features.
5. Write an essay on the significance of seeds in plant survival and dispersal.



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UNIT 1.2

Gymnosperms and Their Classification

Gymnosperms are a group of vascular seed plants that produce **naked seeds**, meaning their ovules are exposed on the surface of cone scales or similar structures rather than being enclosed within an ovary as in flowering plants. The name “gymnosperm” comes from the Greek words *gymnos* (naked) and *sperma* (seed). Gymnosperms are predominantly woody trees and shrubs, often evergreen, and they represent some of the oldest living plant lineages on Earth. They evolved from ancient pteridosperms during the late Paleozoic era and flourished throughout the Mesozoic, often called the “Age of Gymnosperms.”

Structurally, gymnosperms possess well-developed roots, stems, and leaves. Their vascular system consists of xylem and phloem, though the xylem is mostly composed of tracheids and generally lacks vessels. They exhibit secondary growth, producing wood and bark, which allows them to achieve massive sizes and great longevity. Reproductively, they are heterosporous, producing microspores that develop into pollen grains and megaspores that develop into ovules. Fertilization occurs through a pollen tube, eliminating dependence on water for sexual reproduction. Most gymnosperms bear their reproductive organs in cones (strobili), with separate male and female cones on the same or different plants.

Because of their evolutionary and structural diversity, gymnosperms are classified into **four major classes** based on morphology, anatomy, and reproductive traits.

The first class, Cycadopsida (cycads), includes palm-like plants with unbranched stems and a crown of large pinnate leaves. They are dioecious, with distinct male and female plants, and reproduce through large cones. Cycads are considered “living fossils” because they closely resemble ancient forms and have changed little over time; *Cycas* is a well-known example.

The second class, Ginkgoopsida, is represented today by a single surviving species, *Ginkgo biloba*. This tree has distinctive fan-shaped leaves with dichotomous venation. Like cycads, it is dioecious, and its seeds develop on stalks rather than cones. Because it has persisted for millions of years with little change, *Ginkgo* is also regarded as a living fossil and is widely planted for its ornamental and medicinal value.

The third and largest class is Coniferopsida (conifers). These are mostly large, evergreen trees with needle-like or scale-like leaves adapted to conserve water in dry or cold climates. They produce male and female cones, and their seeds are borne on the scales of woody



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female cones. Conifers include economically important genera such as *Pinus* (pines), *Cedrus* (cedars), *Abies* (firs), and *Picea* (spruces), which provide timber, pulpwood, resins, and other products.

The fourth class, Gnetopsida (gnetophytes), consists of plants with some unique traits that show similarities with angiosperms, such as the presence of vessel elements in their xylem. This class includes three very distinct genera: *Ephedra*, a shrub of arid regions; *Gnetum*, a tropical woody climber; and *Welwitschia*, a remarkable desert plant with only two persistent strap-like leaves. These plants are of great evolutionary interest because they bridge certain gaps between gymnosperms and flowering plants.

2.1.1 General Characteristics

Gymnosperms are vascular seed plants that produce *naked seeds*—seeds that are not enclosed within an ovary or fruit. They represent one of the most ancient lineages of seed plants, having originated during the late Paleozoic era and becoming dominant during the Mesozoic. Today, gymnosperms are primarily trees and shrubs found in a wide range of habitats, from cold boreal forests to warm temperate and tropical regions.

1. Plant Body and Habit

The dominant phase in gymnosperms is the **sporophyte**, which is a perennial, woody plant. Most gymnosperms are medium to tall evergreen trees (such as pines and cedars), though some are shrubs or even climbers. They typically exhibit **secondary growth**, producing massive trunks with annual rings of wood and bark. Their body is well differentiated into roots, stems, and leaves, all adapted to life on land.

2. Root System

Gymnosperms have a well-developed **tap root system**, often associated with fungal symbionts (mycorrhizae) that help in water and nutrient absorption. In some cycads, specialized coralloid roots develop, housing nitrogen-fixing cyanobacteria. These roots enable gymnosperms to survive in nutrient-poor soils and harsh conditions.

3. Stem and Leaves

The **stems** of gymnosperms are typically woody and undergo secondary growth, allowing them to reach great heights and ages. Their **leaves** vary in shape and size depending on the group. In conifers, leaves are usually needle-like or scale-like with thick cuticles and sunken stomata to minimize water loss, an adaptation to cold or dry environments. In cycads, leaves are large, pinnate, and resemble palm leaves, while in *Ginkgo*, leaves are fan-shaped with dichotomous venation.



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4. Vascular System

Gymnosperms possess a well-developed **vascular system**. The xylem is primarily composed of tracheids rather than vessels, which makes their wood relatively soft (hence the term “softwood” for many conifers). The phloem contains sieve cells and albuminous cells. The presence of resin ducts in many species helps protect them from herbivory and infection.

5. Reproductive Organs

Gymnosperms are **heterosporous**, producing two types of spores: microspores (male) and megaspores (female). Their reproductive organs are organized into strobili or cones. Male cones produce pollen grains (microspores), while female cones bear ovules on their scales. They are typically unisexual, and most species are monoecious (both male and female cones on the same plant), though some are dioecious.

6. Fertilization and Seed Formation

Fertilization in gymnosperms does **not require external water**. Pollen grains are carried by wind (anemophily) to the ovule, where they form a pollen tube that delivers the sperm to the egg. After fertilization, the ovule develops into a **naked seed**—it is exposed on the surface of the cone scales rather than enclosed within a fruit. In cycads and *Ginkgo*, the male gametes are motile (ciliated), whereas in conifers and gnetophytes, they are non-motile and delivered by the pollen tube.

7. Evergreen Nature and Longevity

Most gymnosperms are **evergreen**, retaining their foliage throughout the year, which allows them to photosynthesize whenever conditions are favorable. Many gymnosperms are remarkably long-lived; for instance, bristlecone pines (*Pinus longaeva*) can live for thousands of years, making them some of the oldest living organisms on Earth.

Examples of evolution and diversity of gymnosperm

The evolutionary history of gymnosperms extends over 300 million years and is a remarkable history of plant adaptation and diversification during radical shifts in Earth's climate and landscape up until today. Gymnosperm evolutionary history is highly informative about the greater evolutionary history of seed plants as well as the origins of major innovations that allowed plants to further occupy and dominate terrestrial habitats. Gymnosperms originated in the Paleozoic (endomycorrhiza fungi) in the late Devonian to early Carboniferous (360-320 million years ago) This period witnessed the emergence of the first seed plants (spermatophytes) from a group of free-sporing, vascular plants, known as progymnosperms, that had already acquired secondary growth and the ability to produce wood but still had no seeds.



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This adaptation later gave rise to the seed where the embryo was protected it had a meal (like the female gametophyte) and it could disperse those means of Transport (animals, air, wind), making it a new technology that revolutionized plant reproduction. This adaptation liberated plants from relying on standing water for reproduction, allowing them to colonize drier environments. The first known seed plants were the seed ferns or pteridosperms (ψτέριδος = "fern"; σπέρμα = "seed"), an informal group (probably paraphyletic) of primitive seed plants with fernlike leaves and reproductive organs producing seeds. Strong examples include the genera *Elkinsia*, *Moresnetia* and *Archaeosperma* during the late Devonian and early Carboniferous. These primitive seed plants possessed the key gymnosperm trait of “naked” seeds, borne on modified leaves rather than enclosing fruits. The period most responsible for this diversification is the Carboniferous (359-299 million years ago), which saw the emergence of several significant lineages of seed plants. The Cordaitales, an extinct order of gymnosperms characterized by large, strap-like leaves and complex reproductive structures, became a major part of Carboniferous forests, alongside lycopsids and ferns. Cordaites were some of the first plants to produce vast forests of large trees, some 30 meters tall or greater. They are an early experiment in the tree growth form that would become more widely adopted by other early gymnosperms. By the late Carboniferous and early Permian periods, other gymnosperm lineages had begun to appear, e.g. the first conifers, cycads, ginkgophytes. The Voltziales, an extinct group of conifers with mixed Cordaitales–modern conifer features, emerged during this period and are regarded as the ancestor of modern conifer families. During the Permian period (299-252 million years ago), gymnosperms continued to diversify while many earlier groups of plants began to decline, paving the way for gymnosperms to dominate the Mesozoic era that followed.

The end-Permian mass extinction, Earth's most catastrophic extinction event, nearly wiped out all marine life (about 95 percent of marine species) and 70 percent of terrestrial vertebrate species some 252 million years ago. It is during this event also that plant communities were also greatly affected, with many Paleozoic plant group going extinct or greatly reduced. Gymnosperms, on the other hand, lived through this bottleneck and exploded in radiations during the following Triassic period, adjusting to the usually hot, dry conditions of the primary Mesozoic environment. Both forms of leaves are a characteristic of a group of plants called gymnosperms, which dominated the landscape during the Mesozoic era (252-66 million years ago), leading the geologic time period to be dubbed the "Age of Gymnosperms." Cycads, ginkgophytes and conifers diversified during the Triassic period (252–201 million years ago) and new groups,



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including the Bennettitales (cycadeoids) and early gnetophytes, emerged. Another immediate group of extinct cycads called the Bennettitales might be familiar, superficially resembling cycads but sporting more complex reproductive structures; they reached great diversity in the Jurassic and early Cretaceous. The Jurassic period (201–145 million years ago) was possibly the peak of gymnosperm diversity and dominance. Conifer-, cycad-, Bennettitales- and ginkgophyte-dominated forests covered much of the land surface, providing habitats for emerging dinosaur faunas. During this period, modern families of conifers became established, including Pinaceae, Araucariaceae, Cupressaceae, and Podocarpaceae, with many genera that remain recognizable today. Ginkgophytes also flourished in the Jurassic, with many species spanning multiple genera compared to just one species surviving to the present. During the Cretaceous (145–66 million years ago), plant evolution underwent a major transition with the emergence and diversification of angiosperms (flowering plants) starting around 140–130 million years ago. As angiosperms diversified ecologically across the Cretaceous, many lineages of gymnosperms declined and became extinct. The end-Cretaceous event, which was triggered by a massive impact from a large asteroid and concomitant extensive volcanic activities 66 million years ago, resulted in pronounced diversity losses among a number of the gymnosperms, and some groups, for example the Bennettitales, completely died out. To this day angiosperms (flowering plants) dominate as the most diverse group of flowering plants on Earth even as gymnosperms (naked seed plants, including ginkgos and conifers) persisted as important elements of Cenozoic (66 million years ago–present day) global vegetation, despite decreased diversity compared to their Mesozoic heyday. While others, like most dinosaurs, soon went extinct, some, particularly some lineages of conifers, persisted and continued to diversify into new ecological niches. Besides angiosperms, other major plant genera offered considerable evolutionary diversification during the Cenozoic, including several that developed adaptations to fire, drought, and cold that allowed them to become dominant in less angiosperm favourable habitats, such as pines (*Pinus*).

This long evolutionary history accounts for the current diversity of gymnosperms, with about 1,000–1,100 extant species being the remnants of once much more diverse lineages. These existing lineages of gymnosperms are not equally distributed among the four divisions. The largest group include the conifers with about 630–700 species, followed by cycads (300–340 species), gnetophytes (70–75 species), and the monotypic Ginkgophyta with the single extant species, *Ginkgo biloba*. The most ecologically successful and extensively represented gymnosperm group in the modern flora are the Pinophyta or conifers. They occupy great forest ecosystems in temperate, boreal, and



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montane regions of both hemispheres. The family Pinaceae, familiar genera being *Pinus* (pines), *Picea* (spruces), *Abies* (firs), and *Larix* (larches), is particularly associated with the Northern Hemisphere, making up the familiar taiga or boreal forest that stretches across North America and Eurasia. The more cosmopolitan family is Cupressaceae, which contains important genera such as *Juniperus* (junipers), *Cupressus* (cypresses), *Sequoia* and *Sequoiadendron* (redwoods), and *Taxodium* (bald cypresses). Entangled in a long history of dispersal and speciation events, the Southern Hemisphere conifer families exemplify distinct biogeographic trends that mirror the break-up of the supercontinent Gondwana throughout the Mesozoic and Cenozoic. The Araucariaceae record a markedly southern distribution; genera include *Araucaria* and *Agathis* in South America and the southern hemisphere, and *Wollemia* in Australia. The Podocarpaceae, in contrast, are mainly Southern Hemisphere, greatest in Australasia and South America. Such patterns offer compelling evidence that gymnosperm distribution and evolution were influenced by continental drift. The Cycadophyta or cycads are a once much more diverse, currently tropical and subtropical only, ancient lineage. The extant species are grouped into three families: Cycadaceae (which has only the genus *Cycas*); Zamiaceae (which includes genera like *Zamia*, *Encephalartos*, and *Macrozamia*); and Stangeriaceae (which consists of the genera *Stangeria* and *Bowenia*). Cycads show fascinating biogeographic patterns with centres of diversity in Mexico, Cuba, Australia, South Africa and Southeast Asia. The various species of cycad have very limited geographical distribution; many of these plants are found in a single country and are classified as threatened or endangered because of habitat destruction and their illegal collection to be used as ornamental plants. The Ginkgophyta was completely dominated by *Ginkgo biloba*, which offers one of the most spectacular examples of evolutionary stasis in the plant kingdom. Mesozoic ginkgo-like plants were common and diverse, with fossils from all continents. The genus underwent a gradual decline through the course of the Cenozoic era, nearly reaching extinction during the Quaternary glaciations. The modern species survived only in a small area of China, where it was preserved in cultivation near Buddhist temples for centuries before being reintroduced to wider cultivation in the 18th and 19th centuries. *Ginkgo biloba* is also widely planted today as an ornamental and street tree in temperate climates around the world, ironically becoming more widespread across the globe through human action than it ever had been over eons by itself.

The gymnosperm division of Gnetophyta (the three genera *Ephedra*, *Gnetum*, and *Welwitschia*) may constitute the most puzzling of all the gymnosperm divisions, at least their morphological features are peculiar and their phylogenetic position remain unclear to date.



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EphedraIt comprises about 40 species of semi-arid and arid shrub plants adapted to both hemispheres. Gnetum consists of approximately 30–35 species of tropical trees, shrubs, and lianas that have wide, angiosperm-like leaves that are widely spread in rainforests in South America, Africa, and Southeast Asia. Welwitschia mirabilis, the only extant representative in the genus, is restricted to the Namib Desert of southwestern Africa and is famous for its strange morphology, comprising a short woody trunk and two permanent strap-like leaves that are continuously produced from their bases over the course of the plant's exceptionally long lifetime (potentially several 1,000s of years). Both the evolutionary relationships among gymnosperm groups and their relationship to angiosperms have been the subject of considerable research and discussion. Such information, as well as traditional morphological analyses, led to several hypotheses, including the anthophyte hypothesis, which claimed that gnetophytes were the closest relatives of angiosperms among all gymnosperms (because of shared features including vessel elements, double fertilization, and reproductive structures somewhat resembling flowers). Genomic phylogenetic studies have subsequently repeatedly shown that all living gymnosperms form a monophyletic group with angiosperms sister to this all living gymnosperms clade, such that any resemblance between Gnetophytes and angiosperms appears to represent convergent evolution rather than relatedness. For gymnosperms, molecular data provides general support for a sister relationship between cycads and Ginkgo with this clade being sister to a clade with conifers and gnetophytes. The placement of gnetophytes has been one of the most contentious aspects of vascular plant phylogenetics, with some analyses recovering gnetophytes as sister to conifers (your gnetifer hypothesis), others placing them within conifers and sister to Pinaceae (the gnepine hypothesis), and even others placing them as sister to all other conifers (the gnecup hypothesis). The still favoured idea from current molecular data is that gnepine represents a specialization of a modified line derived from within the influencing conifer clade.

Gymnosperm diversity is not only expressed in terms of taxonomic richness but also in striking patterns of ecological, morphological and physiological variation. Gymnosperms live in habitats from tropical rainforest to arctic tundra, from sea level to alpine, from wetland to desert. These include the tallest currently living organisms (coast redwoods, Sequoia sempervirens, measuring over 115 meters in height), the most massive individual organisms (giant sequoias, Sequoiadendron giganteum, with single specimens exceeding 2,000 metric tons in mass), and some of the oldest living organisms (bristlecone pines, Pinus longaeva, with single specimens over 4,800 years old). Diversity in gymnosperms is also expressed through a range of morphological adaptations to environmental pressures. Many



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conifer species have well-described adaptations to fire, including thick, insulating bark (e.g., *Pinus ponderosa*), serotinous cones that release seeds in response to heat (e.g., many *Pinus* and *Banksia* species), and resprouting abilities (e.g., *Sequoia sempervirens*). Examples of adaptations to deal with drought include: sclerophyllous leaves, efficient water-conducting system, and expansive root system. Cold adaptations are flexible branches that shed snow, so-called antifreeze compounds in tissues, and deciduous habits in some normally evergreen lineages (e.g., *Larix*, *Metasequoia* and *Taxodium*). The economic and ecological significance of gymnosperms cannot be overstated. They supply timber, pulp, resins, essential oils as well as other products of commercial value. Gymnosperm forests are important ecosystems, forcing global climate feedbacks through carbon sequestration and water cycling, and harbouring food webs for a multitude of organisms. Therefore, the conservation of gymnosperm diversity constitutes not just an issue of conserving evolutionary history, but also one of ensuring ecological function and economic resources. In summary, gymnosperm evolution and diversity is a fascinating chapter in the story of plant life on Earth. Gymnosperms have shown incredible adaptability and evolutionary innovation, from their origins in the Paleozoic, through their dominance in the Mesozoic, to their continued ecological importance today. Their study informs basic processes of plant evolution, biogeography, and adaptation, and their conservation represents fundamental challenges and opportunities for modern biology and ecology.

Summary:

Gymnosperms are seed-producing plants in which seeds are **naked**, i.e., not enclosed within fruits. They are mostly **evergreen, woody trees or shrubs**, adapted to xerophytic conditions. **Vascular plants** with well-developed xylem and phloem. **Heterosporous**: produce **microspores (pollen)** and **megaspores (ovules)**. **Sporophyte dominant**, gametophyte highly reduced and dependent. Reproduction: **wind pollination (anemophily)**, siphonogamy (pollen tube for fertilization), no double fertilization (except *Ephedra*-like “pseudo” case).



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Multiple Choice Question (MCQs):

1. The seeds of gymnosperms are:

- a) Enclosed in fruits
- b) Naked
- c) Without an embryo
- d) Enclosed in ovary

Ans: b) Naked

2. Which of the following is called a "living fossil"?

- a) *Cycas*
- b) *Pinus*
- c) *Ginkgo biloba*
- d) *Ephedra*

Ans: c) *Ginkgo biloba*

3. Which order of gymnosperms shows angiosperm-like features?

- a) Cycadales
- b) Coniferales
- c) Gnetales
- d) Ginkgoales

Ans: c) Gnetales

4. The reproductive structures of gymnosperms are:

- a) Flowers
- b) Cones (strobili)
- c) Sporangia only
- d) Capsules

Ans: b) Cones (strobili)

5. Example of coniferous gymnosperm is:

- a) *Cycas*
- b) *Pinus*
- c) *Ginkgo*
- d) *Gnetum*

Ans: b) *Pinus*



Short Answer Questions

1. Define gymnosperms.
2. Give two examples of conifers.
3. Why are gymnosperms called "naked-seeded plants"?
4. Write two differences between Cycadales and Coniferales.
5. Name one living fossil gymnosperm and justify the term.
6. Mention one angiosperm-like character of *Gnetum*.

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Long Answer Questions

1. Describe the general characteristics of gymnosperms.
2. Explain the classification of gymnosperms with suitable examples.
3. Discuss the economic importance of gymnosperms.
4. Compare and contrast the features of Cycadales, Coniferales, Ginkgoales, and Gnetales.
5. Justify gymnosperms as a "connecting link" between pteridophytes and angiosperms.



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UNIT 1.3

Geological Time scale

The **Geological Time Scale (GTS)** is a chronological framework that divides Earth's 4.6-billion-year history into eons, eras, periods, and epochs. For plants, this scale is extremely important because it shows how vegetation evolved in relation to changes in Earth's climate, continents, and life forms. The fossil record of plants from simple algae to complex flowering plants—reveals stepwise evolutionary advances through geological time.

1.3.1 Precambrian (before 541 million years ago)

In the Precambrian, life was dominated by simple organisms. The earliest photosynthetic life forms, **cyanobacteria**, appeared around 3.5 billion years ago. These microorganisms began releasing oxygen into the atmosphere, setting the stage for future plant evolution. By the late Precambrian (Proterozoic), multicellular algae, such as red and green algae, flourished in oceans, but no land plants existed yet.

1.3.2 Paleozoic Era (541 – 252 million years ago)

The Paleozoic marks the **origin of land plants** and their early diversification.

- **Ordovician Period:** Around 470 million years ago, the first evidence of simple **non-vascular land plants** (like liverwort-like forms) appeared, helping to stabilize soils.
- **Silurian Period:** Vascular tissue evolved; the earliest known vascular plants such as *Cooksonia* emerged, with true stems and sporangia.
- **Devonian Period (Age of Plants):** Plants diversified enormously. **Seedless vascular plants** (ferns, lycophytes, horsetails) spread across continents. **Progymnosperms** and the earliest **seed plants (pteridosperms)** appeared, showing the beginnings of the seed habit.
- **Carboniferous Period:** Vast swampy forests of giant ferns, lycopods, and horsetails dominated, forming the coal deposits we mine today. The first **true gymnosperms** emerged in the late Carboniferous, beginning the seed plant revolution.
- **Permian Period:** Gymnosperms diversified and adapted to drier climates, outcompeting many spore-bearing plants.

1.3.3 Mesozoic Era (252 – 66 million years ago)

The Mesozoic is often called the **Age of Gymnosperms**, as these seed plants dominated landscapes.



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Triassic Period: Gymnosperms such as cycads, ginkgophytes, and conifers were widespread. The first evidence of **early angiosperms** (flowering plants) appears late in this period.

Jurassic Period: Conifers became abundant in vast forests; cycads were common; bennettitales and gnetophytes also thrived.

Cretaceous Period: A revolutionary change occurred with the rapid diversification of **angiosperms (flowering plants)**. They developed flowers and fruits, which improved pollination and seed dispersal. By the end of the Cretaceous, angiosperms began replacing gymnosperms as the dominant vegetation.

Cenozoic Era (66 million years ago – present)

The Cenozoic is often referred to as the **Age of Angiosperms**, as flowering plants dominate almost every terrestrial ecosystem today.

Paleogene and Neogene Periods: Angiosperms diversified into grasses, herbs, shrubs, and large trees. The evolution of **grasses** led to the spread of grasslands, which in turn supported grazing mammals.

Quaternary Period (Ice Ages to present): Modern plant communities formed. Many plant species adapted to repeated glaciations, and humans began domesticating plants, leading to agriculture and the modern biosphere.

Conditions Emerging for Vegetation and Primitive Organisms

When Earth first formed, conditions were extremely hostile intense heat, constant meteorite bombardment, a toxic atmosphere rich in gases like methane and ammonia, and no free oxygen. Over time, as the planet cooled and stabilized, significant changes occurred that created favorable conditions for the emergence of primitive life and, eventually, vegetation. During the early Precambrian, volcanic activity and chemical reactions between the atmosphere and oceans gradually produced water vapor, which condensed into rain, leading to the formation of **early oceans**. These oceans became the cradle of life, offering a stable environment and protection from harsh ultraviolet radiation.

In these primordial waters, the first **primitive organisms** such as simple prokaryotes appeared, likely resembling today's cyanobacteria. They could perform photosynthesis, slowly enriching the atmosphere with oxygen in what is known as the **Great Oxidation Event** (about 2.4 billion years ago). This oxygen buildup laid the foundation for more complex life forms. As atmospheric conditions improved and continents stabilized, shallow coastal regions and nutrient-rich sediments supported the growth of **algae and early photosynthetic organisms**, marking the first steps toward vegetation.



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Over millions of years, these primitive organisms adapted to changing environments. The formation of protective ozone in the upper atmosphere filtered harmful ultraviolet radiation, making surface habitats safer. With improved oxygen levels, diversified niches, and stable climatic conditions, **vegetation slowly transitioned from aquatic to terrestrial environments**. Simple non-vascular plants like moss-like ancestors appeared first on land, followed by vascular plants with supportive tissues and true roots. Thus, the gradual transformation of Earth's physical and chemical environment cooling climate, presence of liquid water, availability of minerals, and oxygen enrichment created the essential conditions for primitive organisms to thrive and for **vegetation to emerge and evolve** into the rich diversity of plant life we see today.

1.3.4 Plant Evolutionary Adaptations Major

The history of plants on Earth is a story of continuous adaptation to changing environments. From simple aquatic algae to complex flowering plants, each major group evolved structural and functional traits that allowed them to survive, reproduce, and spread in new habitats. These **evolutionary adaptations** were not sudden; they developed gradually over millions of years in response to challenges such as desiccation, gravity, nutrient acquisition, and reproduction on land.

1. Transition from Water to Land

The earliest plants were aquatic, like green algae, living in nutrient-rich oceans and freshwater bodies. To colonize land, plants developed a **protective outer covering (cuticle)** to prevent water loss and **stomata** for regulated gas exchange. Supporting tissues like **lignified cell walls** evolved to withstand gravity and maintain upright growth. These adaptations allowed primitive land plants such as bryophytes to survive on moist terrestrial surfaces.

2. Development of Vascular Tissues

A major breakthrough in plant evolution was the development of **vascular tissues**—xylem for water conduction and phloem for food transport. This adaptation first appeared in early pteridophytes and allowed plants to grow taller and exploit sunlight more efficiently while transporting water and nutrients from the soil. Vascular systems also enabled plants to spread into drier areas, leading to extensive forests of ferns, horsetails, and lycophytes during the Paleozoic.

3. Evolution of Seeds

The evolution of the **seed habit** was another critical adaptation. In seed plants (gymnosperms and later angiosperms), the megaspore was retained within the parent tissue, and the developing embryo was



protected by integuments and supplied with stored food. This adaptation eliminated the dependence on free water for fertilization and provided a durable, dormant stage that could withstand harsh conditions. Seeds also facilitated wide dispersal, giving gymnosperms a dominant role during the Mesozoic.

4. Origin of Flowers and Fruits

In angiosperms, the development of **flowers** represented an advanced reproductive adaptation. Flowers evolved to attract specific pollinators (insects, birds, bats), ensuring more efficient and cross-pollination. The **enclosure of ovules within an ovary** that matures into a **fruit** provided further protection for seeds and promoted diverse dispersal strategies—by wind, water, or animals. These innovations led to the explosive diversification and ecological dominance of flowering plants.

5. Co-evolution and Specialized Structures

As plants adapted, they co-evolved with animals and changing climates. Many developed **specialized leaves** (spines in cacti, needle leaves in conifers) to conserve water in arid habitats, or broad leaves in rainforest species to capture sunlight. Some evolved **storage organs** like tubers, bulbs, and rhizomes to survive seasonal changes. Others developed symbiotic relationships, such as root nodules housing nitrogen-fixing bacteria or mycorrhizal associations enhancing nutrient uptake.

1.3.5 Mass Mobility and Its Significance for Flora

The term **mass mobility** refers to the large-scale movement or migration of plant propagules such as seeds, spores, or vegetative parts—across regions through natural agents or human activities. In the context of plant evolution and ecology, mass mobility is a key factor that has shaped the distribution, diversity, and survival of flora across the globe. Plants themselves are sessile, but their reproductive units are highly mobile, and this mobility has immense significance for both natural ecosystems and human societies.

Natural Agents of Mass Mobility

Plants have evolved numerous adaptations for dispersal, allowing their seeds and spores to travel long distances. **Wind dispersal** (anemochory) enables lightweight seeds with wings or hairs, such as those of pines, maples, and dandelions, to move far from the parent plant. **Water dispersal** (hydrochory) allows buoyant seeds like those of coconut to cross seas and colonize islands. **Animal-mediated dispersal** (zoochory) plays a major role: seeds with hooks cling to fur or feathers, while fleshy fruits are eaten and their seeds deposited elsewhere. These forms of natural mass mobility prevent



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overcrowding, reduce competition among offspring, and promote gene flow among distant populations.

Human-Mediated Mass Mobility

With the advent of agriculture, trade, and travel, humans became one of the most powerful agents of mass mobility for flora. Crops such as wheat, rice, maize, and potatoes have been transported far from their centers of origin, reshaping global vegetation patterns. Ornamental plants, medicinal species, and timber trees have been carried across continents, creating new opportunities for biodiversity in gardens, plantations, and forests. However, human-mediated mobility also introduces invasive species that can disrupt native ecosystems.

1.3.6 Significance for Evolution and Biodiversity

Mass mobility has profound evolutionary implications. By moving propagules over large areas, it **enhances genetic mixing** between populations, which leads to greater variation and adaptability. Plants dispersed to new environments face different climatic and ecological pressures, driving **natural selection and speciation**. Island floras, for instance, are largely the result of long-distance seed dispersal and subsequent evolutionary radiation. The global distribution of many modern plant families is a direct outcome of such mobility over millions of years.

Ecological and Conservation Significance

Mass mobility is crucial for the **stability and resilience of ecosystems**. When plants colonize new areas, they establish vegetation cover that stabilizes soils, moderates local climates, and provides habitats for other organisms. In restoration ecology, understanding seed mobility helps in re-vegetating degraded lands. Conservation programs often mimic natural mass mobility by collecting and spreading seeds to rebuild plant populations and safeguard endangered species.

Summary:

The Geological Time Scale (GTS) is a chronological framework that divides Earth's 4.6-billion-year history into major units of time such as



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eons, eras, periods, and epochs. The **Precambrian** (4600–541 million years ago) was the longest span, marked by the origin of life, prokaryotes, eukaryotes, and simple multicellular organisms. The **Paleozoic Era** (541–252 mya), called the “Age of Ancient Life,” witnessed the Cambrian Explosion, the rise of fishes, amphibians, reptiles, and the first land plants. The **Mesozoic Era** (252–66 mya), known as the “Age of Reptiles,” was dominated by dinosaurs and saw the origin of mammals and birds, ending with a mass extinction. The **Cenozoic Era** (66 mya–present), the “Age of Mammals,” is characterized by the diversification of mammals, birds, and angiosperms, with humans evolving in the Quaternary period. Thus, the Geological Time Scale provides a systematic record of Earth’s evolutionary and geological history.

Multiple Choice Question (MCQs):

1. Which is the oldest eon in Earth’s history?

- a) Phanerozoic
- b) Archean
- c) Proterozoic
- d) Hadean

Ans: d) Hadean

2. The "Age of Reptiles" refers to:

- a) Precambrian
- b) Paleozoic
- c) Mesozoic
- d) Cenozoic

Ans: c) Mesozoic

3. The Quaternary period belongs to which era?

- a) Paleozoic
- b) Cenozoic
- c) Mesozoic
- d) Precambrian

Ans: b) Cenozoic



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4. Which period is known for the Cambrian Explosion of life?
- a) Ordovician
 - b) Silurian
 - c) Cambrian
 - d) Devonian

Ans: c) Cambrian

5. The extinction of dinosaurs occurred at the end of:
- a) Devonian period
 - b) Jurassic period
 - c) Triassic period
 - d) Cretaceous period

Ans: d) Cretaceous period

Short Answer Questions

- 1. Define Geological Time Scale.
- 2. Name the three major eras of Phanerozoic eon.
- 3. Which era is called the "Age of Mammals" and why?
- 4. In which era did the first land plants appear?
- 5. Name the period in which humans evolve

Long Answer Questions

- 1. Describe the major divisions of the Geological Time Scale with key events.
- 2. Discuss the life forms of the Paleozoic, Mesozoic, and Cenozoic eras.
- 3. Explain the significance of mass extinctions in shaping the Earth's biodiversity.
- 4. Write an essay on the importance of the Geological Time Scale in evolutionary studies.
- 5. Compare Precambrian life with Phanerozoic life forms.

UNIT 1.4

Fossilization and fossil gymnosperm



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Re-examined fossilization processes and fossilization processes of gymnosperms could help provide an interesting window to our knowledge of the evolutionary history of seed plants and how their evolution changed across geological time. Gymnosperms are one of the earliest groups of seed-bearing plants, and they have also deposited a rich fossil record over the last 300 million years, offering potentially important information about plant evolution, ancient ecosystems, and changes in climate over geological timescales. This exploration covers the complex mechanisms of fossilization, the different kinds of organisms preserved in the geological record, the techniques used to date such remains, and the rich diversity of fossil gymnosperms discovered and studied by paleobotanists around the globe.

1.4.1 Fossilization

Fossilization is an incredible natural process whereby the remains of organisms are retained in the geological record of the Earth. Upon the death, an organism begins a complex series of chemical and physical changes over extremely long periods of time (often millions of years). A series of events must happen, in the right conditions, for a plant to become fossilized a rare occurrence that describes why only a tiny fraction of all lifeforms that have ever lived become fossilized. The process of becoming fossilized begins with rapid burial that shields the organism from scavengers, bacterial decay, and physical degradation by environmental elements, including wind and water. As for plants which also includes gymnosperms they are often buried in sedimentary environments such as a riverbed, lakeshore, delta, or an area where ash from a volcanic eruption has settled. The sediments that bury the plant material form an anoxic environment that greatly halts the breakdown of the plant, allowing preservation to take place. After burial, the plant debris is subject to diagenesis the progressive physical and chemical alteration of the organic matter into a more stable end product. At this time, mineral-rich groundwater will percolate through the buried plant material, slowly replacing the original organic-derived compounds with minerals such as silica, calcite, or pyrite in a process called permineralization. These minerals fill in the cellular structures of the plant, forming a stone-like copy of the original plant that preserves exceptional detail of the original tissues, sometimes to the cellular level. In some instances, the plant material will not be permineralized, as increasing heat and pressure will progressively drive off volatile elements (such as hydrogen, oxygen and nitrogen), leaving behind a carbon-enriched residue known as carbonification. This process is implicated in the formation of coal deposits and the thin carbon films



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that often image leaves and other fine plant structures preserved in the fossil record.

Few plant parts get fossilized, only specific tissue types and specific geological settings favor fossilization. Woody (or xylem) tissues, with thick cell walls heavily impregnated with lignin, are more likely to fossilize than softer tissues. Likewise, plants that live in or adjacent to aquatic systems, where rapid sediment burial is relatively common, have an enhanced chance to become part of the fossil record. These biases in preservation pose challenges to paleobotanists working to reconstruct ancient plant communities based solely on fossils. Fossil specimens can be preserved to highly variable degrees. In rare situations, called conservation lagerstätten, environmental conditions produce fossils with incredible detail and completeness. For example, certain gymnosperm fossils found in volcanic ash deposits show cellular details like preserved nuclei and organelles. Such remarkable preservation provides valuable insights into the anatomical and physiological characteristics of ancient plants that otherwise would have remained unknown. Taphonomy, the science of how an organism becomes a fossil, shows that physical forces will often transport and sort parts of plants before burial. The result is that various sections from the same plant — leaves, stems, seeds and pollen — can get torn apart and fossilized in different places, making it tough for botanists trying to put together whole plants from disconnected fossil bits. This has led to numerous examples in which separate taxa were described based on only one part of a multi-part organism, which, when discovered, were ultimately connected to the same gymnosperm species. The process of fossilization also interacts with an ever-changing geological context. If tectonic forces alter the Earth's geography over millions of years, fossils that once lay buried can be uncovered, whether through forces of uplift or erosion, making them available to human discovery. Fossils can also be metamorphosed, when the rocks they are in are subjected to extreme heat and pressure, and the conditions of metamorphism will destroy the cellular and chemical structures that the body originally preserved. The slow fossilization processes are complex, and understanding them provides critical context to interpret the gymnosperm fossil record. It reminds paleobotanists that the fossil record is only a small, biased sampling of past gymnosperm diversity. It is important to note that while these are some of the limitations associated with the fossil record of gymnosperms, the fossil evidence provides a unique insight into the evolutionary history of these plants and the ecosystems in which they existed over geological time.erro

1.4.2 Types of Fossils

Fossils are the preserved remains, impressions, or traces of plants and animals from past geological ages. They provide direct evidence of ancient life and are crucial for understanding evolution and the history of Earth's flora and fauna. In plants, fossils record the transition from simple algae to complex seed plants. Based on how they are formed and what is preserved, fossils are broadly classified into several types.

1. Petrified or Mineralized Fossils

Petrified fossils are formed when the original plant material is gradually replaced by minerals over time, while maintaining the original structure. Groundwater rich in dissolved minerals like silica, calcium carbonate, or pyrite percolates through buried plant material. The minerals fill the cell walls and spaces, preserving microscopic details such as growth rings and tissues. For example, fossilized wood from extinct conifers is often found as petrified logs in ancient forests.



Fig. 1.3 Petrified or Mineralized Fossils

2. Moulds and Casts

When a plant part like a leaf, seed, or stem is buried in soft sediment, it may decay and leave an impression or hollow. This impression is called a **mould fossil**. If the mould later fills with minerals or sediments, it forms a **cast fossil**, which is a three-dimensional replica of the original structure. Leaf impressions and stem casts are common in sedimentary rocks from coal-forming periods.

3. Compression Fossils

Compression fossils occur when plant material is buried under layers of sediment and subjected to pressure. The volatile components escape, leaving a thin carbon film that retains the outline and surface features of the plant. These fossils often show fine venation patterns of leaves or frond details. They are particularly abundant in shales from ancient swamp forests.



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Fig.1.4 Compression Fossils

4. Impression Fossils

Impression fossils are superficial imprints left by plant parts on soft sediments. Unlike compression fossils, they contain no organic material—only the surface pattern remains. For example, the impression of a fern leaf may be seen in fine-grained sandstone or siltstone, showing venation and margins in detail.

5. Amber or Resin Fossils

In some cases, plant parts such as leaves, seeds, or even small flowers and insects get trapped in sticky plant resin. Over millions of years, this resin hardens into **amber**, perfectly preserving the enclosed specimens in three dimensions. Amber fossils are invaluable because they capture delicate structures that would otherwise decay, including ancient pollens and tiny plant fragments.

6. Coal and Peat as Fossil Plant Material

Large accumulations of plant material in ancient swamps, when subjected to geological pressure and heat, transform into **peat**, then lignite, and eventually **coal**. Although not preserving specific structures, coal is considered a massive fossil deposit that records the abundance of ancient vegetation, particularly from the Carboniferous period.

1.4.3 Fossil Dating Methods

Understanding the age of fossils is essential for reconstructing the history of life and placing evolutionary events on a timeline. Scientists use several dating methods, broadly grouped into **relative dating** and **absolute dating**, to determine when the organism lived. These methods rely on principles of geology, chemistry, and physics and have greatly improved our knowledge of plant and animal evolution.

1. Relative Dating



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Relative dating methods do not provide an exact age but establish whether a fossil is older or younger than other fossils or rock layers. The most common approach is the **principle of superposition**, which states that in undisturbed sedimentary rocks, lower layers are older than those above them. By studying the sequence of rock strata and comparing the fossils within them, scientists can build a relative chronology. **Biostratigraphy**, which uses index fossils (fossils of species known to have existed during specific time intervals), helps correlate rock layers across different regions.

2. Radiometric or Absolute Dating

Absolute dating methods provide a more precise age by measuring the decay of radioactive isotopes in minerals surrounding or within fossils. For example, **radiocarbon dating (C-14 method)** is widely used for fossils up to about 50,000 years old, as it measures the decay of carbon-14 in organic material. For older fossils, methods such as **potassium–argon (K–Ar) dating**, **uranium–lead (U–Pb) dating**, and **argon–argon (Ar–Ar) dating** are applied to volcanic layers associated with the fossil. These techniques can date rocks that are millions of years old, helping to establish the age of ancient plant remains and petrified forests.

3. Dendrochronology and Other Methods

In some cases, especially for more recent plant fossils or wood samples, **dendrochronology** (tree-ring dating) can be used. Each ring in a tree trunk represents one year of growth, and by comparing ring patterns in living and fossilized wood, researchers can determine both age and past climatic conditions. Additionally, methods like **thermoluminescence dating** or **optically stimulated luminescence (OSL)** can determine the last time minerals in sediments were exposed to sunlight or heat, helping date the layers in which fossils are found.

1.4.4 Fossil Gymnosperms

Fossil gymnosperms include an incredibly diverse assemblage of extinct seed plants, which dominated Earth's terrestrial ecosystems for hundreds of millions of years prior to the evolution of flowering plants. The class comprises ancient seed-bearing plants, whereby the term "naked" refers to un-enclosed seeds as fruits, extant members of which exhibit a wide paleontological record that documents their evolutionary history from Late Paleozoics into Mesozoics and advance to the present day. This record not only provides evidence of their morphological diversity and evolutionary innovations but also of their ecological adaptations and responses to major environmental changes through geological time. And they first emerged during the Late Devonian and Early Carboniferous, around 360 to 345 million years ago: the earliest



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definitive gymnosperms. These very early seed plants (with examples including *Elkinsia* and *Archaeosperma*) reflected a revolutionary innovation in plant reproduction—the seed habit. Land plants faced a challenge of reproducing in a new terrestrial world, and these fossils capture some early solution, with ovules surrounded by cupule-like structures. While morphologically distinct from their modern gymnosperm descendants, these early plants established the basic reproductive strategy that would unify all seed plants to come. Say what you will about how dinosaurs were killed and the history of birds as a result, but the quality of preservation in the Pennsylvanian coal balls of North America have led to some controversial ideas about the anatomical details of these early seed plants, including how they came to have the integrated vascular, structural and reproductive systems that would one day prove so evolutionarily successful. By the Middle to Late Carboniferous (around 320–300 million years ago), gymnosperms had diversified into a number of lineages. Genera such as *Cordaites* in the Cordaitales gave rise to large trees with strap-like leaves and elaborate reproductive structures. Their permineralized stems indicate advanced wood anatomy, with a well developed secondary xylem, showing an early capacity for substantial vertical growth. In the case of coal measures cordaitaleans of the Carboniferous of Europe and North America, vegetative structures, as well as pollen and other organiferous parts bearing seeds, are preserved which has allowed paleobotanists to reconstruct their reproductive biology in some detail. Their pollen cones (*Cordaianthus*) produced saccate pollen like modern conifers, and their seeds showed structuring complexity anticipating the reproductive innovations seen in later gymnosperms.

The seed ferns (the “pteridosperms”) diversified widely during the Carboniferous and Permian, contemporaneously with the Cordaitales. These plants, which included lineages like *Medullosales* and *Callistophytales*, had an interesting morphology which combined fern-like foliage with reproductive structures producing seeds, and made such an agreeable morphology that paleobotanists historically viewed it as a transitional state between ferns and seed plants. Superb fossils from sites like Mazon Creek in Illinois preserve medullosan seed ferns with even stunning three-dimensional detail showing large seeds directly attached to frond-like leaves a reproductive arrangement totally unlike that of extant gymnosperms. Hence, amphiphloic xylem and phloem, which are visually impressive, bear the anatomical complexity of “polystelic” plants with potential physiological sophistication and the ability to grow very tall in late Paleozoic tropical coal swamps. A further diversification of gymnosperm lineages, including the completely characteristic *Glossopteridales* protagonists within the only Gondwanan supercontinent increased any through the Permian amount. *Glossopteris* and similar genera had characteristic tongue-



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shaped leaves with distinctive net venation, and were highly differentiated from other gymnosperms known from the same time. Seed-bearing organs which can be assigned to *Dictyopteridium* and pollen-bearing organs which can be assigned to *Eretmonia*, indicating a greater level of reproductive complexity than previous seed plants. The almost universal occurrence of these fossils on present-day southern continents gave rise to some of the first paleobotanical evidence in support of continental drift theory, since these plants could not have spread across the current oceans separating these landmasses. The end-Permian mass extinction, around 252 million years ago, drastically reshaped gymnosperm diversity, eradicating many Paleozoic lineages. During the following Triassic, groups of gymnosperms which were better suited to the changing environmental conditions emerged. The extinct family *Voltziaceae*, believed to be closely aligned to modern conifers, were prominent elements of early Mesozoic forests. They are particularly well preserved in the Middle Triassic deposits of Europe and East Greenland and document a critical transitional phase in conifer evolution, with reproductive cones intermediate in morphology between the more primitive structures of Paleozoic gymnosperms and the more derived, complex cones of modern conifer families. The Triassic also saw the radiation of cycadophytes, including true cycads and the extinct cycadeoids (Bennettitales). Fossils of cycads like *Bjuvia* and *Pseudoclenis* preserve the distinctive pinnately compound leaves which are still recognizable in their modern relatives. Permineralized cycad stems from this era preserve anatomical detail, suggesting the characteristic armored trunk structure and specialized vascular architecture that define this ancient lineage. In parallel, the cycadeoids evolved homoplasiously with their own reproductive structures that display astonishing convergence with angiosperm flowers, with simple pollen-producing organs organized around a central receptacle with structures bearing the ovules. The zenith of gymnosperm dominance and diversity occurred in the Jurassic period (201-145 million years ago). Typically known as the "Age of Cycads", it was during this interval that cycadophytes continued to undergo substantial radiation and conifer lineages began to modernize. In contrast, the exceptional preservation at Jurassic lagerstätten such as the Liaoning deposits of China has yielded impressively complete cycadeoid specimens, including *Williamsonia* with its reproductive structures intact and exhibiting individual anatomical features in detail. Merely presumed to be an extinct flowering plant species for years, these fossils show that cycadeoids had intricate reproductive anatomy and could have had insect pollination systems, challenging former concepts of gymnosperm fertilisation as being solely wind-mediated.



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The Jurassic was an important time for the diversification of conifers including many families known today. Modern *Araucaria* and *Agathis* have maintained one of the distinctive aspects of their cone morphology—one seed per scale—establishing this feature in the Mesozoic *Araucariaceae*, exemplified by the genus *Araucarites*. (The *Cheirolepidiaceae*, now-extinct family of conifers, reached extraordinary abundance during the Jurassic and Cretaceous.) *Classopollis*, their unique type of pollen, dominates several palynological assemblages from the Mesozoic, identifying them as an ecologically important group. It emerges that exceptionally preserved *cheirolepidiaceae* fossils from the Cretaceous of Lebanon, the preservation medium being amber, allows us to provide data on their shoot morphology and resin production that account for their evolutionary success in an age of increasing aridity and seasonality. Ginkgophytes (middle Jurassic to early Cretaceous) -- Fan shaped leaves The fossil groups *Ginkgoites* and *Baiera* show much wider morphological diversity than the single living species, *Ginkgo biloba*. Fossils of complete ginkgophytes from the Jurassic Yanliao Biota of China preserve not only leaves but also reproductive structures, attesting to the antiquity of the unique seed morphology and two motile sperm cell type found in this lineage. Comparative global distribution of ginkgophyte fossils during the Mesozoic, versus the natural range of the single surviving species, demonstrates the striking range contraction this formerly diverse group of plants has witnessed. The angiosperms (flowering plants), the fate of a dominant lineage of seed plants, were introduced in the Cretaceous, where they diversified rapidly and posed new challenges for the gymnosperms. Gymnosperms, on the other hand, were certainly not idle during this time! The *Pinaceae*, the most diverse family of conifers today, became progressively more abundant in the fossil record, with genera like *Pityostrobus* showing development of the unique morphology of cones that we see in extant pines, spruces and firs. Remarkable fossils from the Early Cretaceous Jehol Biota of China preserve pinaceous remains showing sufficient anatomical detail to recognize their specific relationships with modern genera, and thus serve as calibration points for molecular clock studies of conifer evolution. Seed cones of extinct *cupressaceous* conifers like *Protocupressinoxylon* from the Cretaceous of Antarctica show that the distinctive flattened cone scales of cypresses and their relations had evolved by then. *Podocarp* fossils from the Cretaceous of Argentina similarly retain the fleshy seed receptacles that remain a defining feature of this southern hemisphere conifer family. The fossils provide a record of the development of the unique reproductive strategies used by living conifer families that allows them to endure in the face of angiosperm competition. During the Cenozoic (greatest 66 million years), gymnosperm range evidently reduced compared to angiosperms, but these cash plants remained



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ecologically important in countless biomes. Fossils show that broadly-distributed clades slowly became restricted to their current relictual distributions. *Metasequoia* (the dawn redwood) is an example of this pattern—once spread across the Northern Hemisphere in the Paleogene, it went extinct in North America and Europe in the Neogene cooling, surviving in only a few localities in China. Its discovery as a living fossil in 1944 dramatically illustrated how deeply entombed in the fossil record lie lineages of gymnosperms that narrowly escaped complete extinction. Related, fossils of *Sequoia* and *Sequoiadendron* from western states, such as Wyoming and Colorado, document the transcontinental former distribution of these iconic conifer genera that today are restricted to California and a few adjacent areas. The remarkable preservation of these fossils, in some instances to the level of anatomical detail visible with electron microscopy, enables comparisons with extant members that show the morphological conservatism these long-lived lineages of gymnosperms often take on (Cenomanian–Turonian fossils of the Australian dwarf conifer genus *Wollemia* are significant among them).

The Quaternary fossil record covering the last ≈ 2.6 million years documents gymnosperm responses to the extreme climate inconstancy of the ice ages. Gymnosperm species tracked suitable climate conditions, as preserved in conifer macrofossils and pollen from lake sediments, peat bogs, and packrat middens indicate latitudinal and elevational range shifts. This fossil record now provides unique opportunities to investigate exactly the same climates to which modern gymnosperm species of alternative success have been acclimatized, and equip ourselves with knowledge on how these ancient plants may respond under similar conditions of current climate change. The extraordinary preservation found in ancient packrat middens from the American Southwest, for example, has recorded the slow retreat of conifer species to higher elevations over the last 10,000 years in response to regional warming after the last glacial maximum. Fossil gymnosperms have shown great adaptability to a changing environment throughout their extensive evolutionary history. Their anatomical characters, beautifully preserved in permineralized fossils, record responses to water stress, seasonality and differing light regimes. Fossil conifer wood, showing distinct growth rings from the Jurassic and Cretaceous in particular, provides evidence of seasonality even in these mostly warm geological periods. Successively, the sunken stomata and thick cuticles retained in Cretaceous fossil conifer leaves record adaptations to conserve water that recapitulate those of contemporary drought-adapted taxa. Fossil gymnosperm reproductive biology—unmasked by meticulous extraction and analysis of intact pollen and seed structures—charts a transition to ever more refined reproductive strategies. Specialized adaptations for efficient pollen



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capture with the development and function of elaborate pollination drops and aerodynamic pollen of some Mesozoic conifers (Miller et al., 2004) highlights a strategy of extreme divergence in the separation of the male and female reproductive structures, one of the hallmarks of the gymnosperms. These reproductive innovations, preserved in fossilized form, shed light on how gymnosperms attained such ecological dominance preceding the evolution of flowering plants and how they thrive in the face of angiosperm competition in some environmental settings to this day.

1.4.1.1 Types of Fossil Gymnosperms

Gymnosperms, the “naked seed” plants, have a long evolutionary history dating back to the Paleozoic era. Many groups that once flourished are now extinct, but their remains are preserved in the fossil record. These **fossil gymnosperms** reveal the evolutionary transition from primitive seed ferns to the highly specialized conifers and cycads of today. On the basis of their morphology and geological occurrence, several distinct types of fossil gymnosperms are recognized.

1. Pteridosperms (Seed Ferns)

Pteridosperms were among the earliest gymnospermous plants, abundant during the late Paleozoic (Carboniferous and Permian periods). They looked like large ferns with fronds but reproduced through seeds rather than spores. Their ovules were borne on modified leaf structures rather than enclosed in cones. Pteridosperms are considered a **transitional group** between true ferns and later gymnosperms, showing how the seed habit first evolved. Fossils of genera like *Lyginopteris* and *Medullosa* are classic examples.

2. Cycadeoideales (Bennettitales)

These extinct gymnosperms were prominent during the Mesozoic, especially the Jurassic and Cretaceous periods. Cycadeoideales were small to medium-sized plants with thick, woody stems and a crown of leaves resembling cycads. Their reproductive structures were highly specialized, often with complex flower-like arrangements. Fossils such as *Williamsonia* and *Cycadeoidea* reveal features that show parallels with both cycads and angiosperms, making them significant in studies of flowering plant evolution.

3. Cordaitales

Cordaitales were tall, tree-like gymnosperms dominant in the late Paleozoic, particularly the Carboniferous. They had slender trunks, strap-like leaves, and reproductive structures arranged in cones. These plants are believed to be closely related to the ancestors of modern



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conifers. Fossil evidence of *Cordaites* shows adaptations to swampy habitats and provides insight into the shift from primitive gymnospermous forms to more advanced groups.

4. Pentoxylales

Pentoxylales were an unusual group of gymnosperms known from the Jurassic of India and some other regions. They had slender stems with prominent leaf scars and compound leaves. Their reproductive structures were unique, with clusters of ovules and complex male organs. Though short-lived in geological history, they are important fossils because they demonstrate experimentation in plant evolution during the Mesozoic.

Summary

Besides the major groups above, there were other extinct gymnospermous plants such as **Caytoniales**, which showed some angiosperm-like features in their seed structures, and **Glossopterids**, abundant in Gondwana during the Permian, whose seeds and leaves are commonly found in coal measures. These groups illustrate the diversity of gymnosperms before flowering plants became dominant.

SELF ASSESSMENT QUESTIONS

Multiple Choice Questions (MCQs):

1. Which of the following is a characteristic feature of seed plants?
 - a) Absence of vascular tissues
 - b) Production of seeds for reproduction
 - c) Presence of spores instead of seeds
 - d) Lack of roots and stems

Ans. b) Production of seeds for reproduction

2. Which two main groups classify seed plants?
 - a) Gymnosperms and Angiosperms
 - b) Bryophytes and Pteridophytes
 - c) Algae and Fungi
 - d) Ferns and Mosses

Ans. a) Gymnosperms and Angiosperms

3. What is the main advantage of seed habit evolution?
 - a) Dependence on water for fertilization
 - b) Protection and nourishment of the embryo
 - c) Production of spores instead of seeds
 - d) Decreased adaptability to environmental changes



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Ans. b) Protection and nourishment of the embryo

4. Gymnosperms differ from angiosperms because:
- a) They produce seeds enclosed in fruit
 - b) They lack vascular tissues
 - c) Their seeds are exposed and not enclosed in an ovary
 - d) They reproduce through spores

Ans. c) Their seeds are exposed and not enclosed in an ovary

5. Which of the following is NOT a division of gymnosperms?
- a) Cycadophyta
 - b) Coniferophyta
 - c) Ginkgophyta
 - d) Pteridophyta

Ans. d) Pteridophyta

6. The geological time scale is used to:
- a) Classify animals only
 - b) Determine the structure of modern plants
 - c) Study the history and evolution of life on Earth
 - d) Examine only fossilized bacteria

Ans. c) Study the history and evolution of life on Earth

7. The oldest known seed plants appeared during which geological era?
- a) Cenozoic
 - b) Paleozoic
 - c) Mesozoic
 - d) Precambrian

Ans. b) Paleozoic

8. Which of the following is a method for dating fossils?
- a) Carbon dating
 - b) Genetic sequencing
 - c) Water absorption test
 - d) Electromagnetic radiation

Ans. a) Carbon dating

9. The process of converting organic material into a fossil is called:
- a) Erosion
 - b) Fossilization
 - c) Decomposition
 - d) Sedimentation

Ans. b) Fossilization



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10. What type of fossil preserves the entire structure of an organism?
- a) Trace fossil
 - b) Cast fossil
 - c) Amber fossil
 - d) Imprint fossil

Ans. c) Amber fossil

Short Answer Questions:

1. What are the defining characteristics of seed plants?
2. How are seed plants classified?
3. Why is the evolution of the seed habit considered an important adaptation?
4. Differentiate between gymnosperms and angiosperms.
5. What are the main divisions of gymnosperms?
6. Define the geological time scale and its significance in plant evolution.
7. What are the major evolutionary adaptations of plants over time?
8. How did mass extinctions impact plant evolution?
9. What is fossilization, and how does it occur?
10. Name and explain different types of fossilization processes.

Long Answer Questions:

1. Explain the classification of seed plants and their evolutionary significance.
2. Discuss the key characteristics and adaptations of gymnosperms.
3. Describe the geological time scale and how it relates to plant evolution.
4. What are the major plant evolutionary adaptations seen over different geological periods?
5. Explain the role of mass extinctions in shaping plant diversity.
6. What is fossilization? Discuss the different types of fossilization processes.
7. Compare and contrast fossil and living gymnosperms, giving examples.



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8. What are the different fossil dating methods, and how do they work?
9. Discuss the importance of fossilized plants in understanding past climates and environments.
10. Explain the significance of gymnosperms in the fossil record and their contribution to modern plant evolution.

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MODULE -2

GYMNOSPERM



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2.0 Objectives

- Understand the vegetative and reproductive morphology of gymnosperms.
- Learn about the anatomical features of *Pinus*, *Cycas*, and *Ephedra*.
- Explore the reproductive cycles of selected gymnosperms.
- Identify the economic and cultural significance of gymnosperms.

UNIT 2.1

Morphology of vegetative and reproductive parts of Gymnosperm

Plant morphology, the study of the physical form and external structure of plants, provides insight into plant function, their adaptation and evolution. This survey of plant morphology considers both vegetative structures (roots, stems, and leaves) and reproductive structures (flowers, fruits, seeds, and specialized reproductive structures for the non-flowering plants). These morphological traits are basic knowledge in the field of botany from classification of plants, ecological based studies and agricultural uses. **Gymnosperms** are ancient seed plants characterized by *naked seeds* borne on the surface of cone scales or similar structures. Their morphology reflects adaptations for survival in diverse habitats and efficient reproduction without the need for water. Below are the details of their **vegetative** and **reproductive** structures.

2.1.1 Vegetative Morphology

Habit and Body Plan: The dominant phase in gymnosperms is the **sporophyte**, which is a perennial, woody plant. Most gymnosperms are medium to tall **evergreen trees** (e.g., *Pinus*, *Cedrus*) and some are shrubs (e.g., *Ephedra*). The plant body is clearly differentiated into **roots, stems, and leaves**.

Root System: Gymnosperms usually possess a well-developed **taproot system**. Many have **coralloid roots** (as in *Cycas*) that house nitrogen-fixing cyanobacteria. Mycorrhizal associations are also common, aiding nutrient uptake in poor soils.

Stem: Stems are **woody**, showing prominent **secondary growth** due to the activity of vascular cambium. The xylem mainly consists of **tracheids** (hence their wood is often termed *softwood*) and lacks



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vessels, except in Gnetophytes. Resin ducts are often present, secreting resin that protects the plant from herbivores and pathogens.

Leaves: Leaves are typically **simple** and adapted to their environment. In conifers like *Pinus*, they are **needle-like** with thick cuticle and sunken stomata, reducing water loss. In cycads, leaves are **large, pinnately compound**, resembling ferns. *Ginkgo* has **fan-shaped leaves** with dichotomous venation. Most gymnosperms are evergreen, retaining leaves year-round.

2.1.2 Reproductive Morphology

Reproductive Nature: Gymnosperms are **heterosporous**, producing microspores (male) and megaspores (female). The reproductive organs are generally arranged in **cones (strobili)**.

Male Reproductive Structures (Microsporangiate Strobili): Male cones are typically smaller and bear numerous **microsporophylls**, each with **microsporangia** that produce pollen grains. Pollen grains (male gametophytes) often have air sacs for wind dispersal. For example, in *Pinus*, the male cone is simple, with spirally arranged microsporophylls.

Female Reproductive Structures (Megasporangiate Strobili): Female cones are larger and consist of **megasporophylls** bearing ovules on their upper surface. The ovule is not enclosed in an ovary; it consists of a **nucellus** surrounded by **integuments**, leaving a micropyle for pollen entry. In cycads, ovules are borne on leaf-like megasporophylls, while in conifers, they are on woody scales.

Pollination and Fertilization: Pollination is typically by **wind (anemophily)**. Pollen grains reach the micropyle, germinate, and form a **pollen tube** to deliver sperm cells to the egg. Fertilization is independent of free water. In some primitive gymnosperms (e.g., *Cycas*, *Ginkgo*), the sperm is motile and multiflagellate, but in most conifers, sperm is non-motile.

Seed Formation: After fertilization, the ovule develops into a **naked seed** with three components:

- **Embryo** (young sporophyte),
- **Stored food** (female gametophyte tissue),
- **Seed coat** (developed from integuments). Unlike angiosperms, there is no enclosing fruit; seeds are exposed on the surface of cone scales.



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Summary:

Gymnosperms are mostly perennial, evergreen, woody trees or shrubs with a well-developed tap root system; in some cases like *Cycas*, coralloid roots occur in association with cyanobacteria for nitrogen fixation. The stem is erect, woody, and may be branched as in *Pinus* or unbranched as in *Cycas*, showing secondary growth. Leaves are dimorphic—large pinnate foliage leaves in *Cycas* or needle-like in *Pinus* for photosynthesis, and small scale leaves for protection; xerophytic features like thick cuticle and sunken stomata are common. Reproductively, gymnosperms are heterosporous and bear cones (strobili). Male cones consist of microsporophylls with microsporangia producing pollen grains, while female cones have megasporophylls bearing ovules on their surface. Pollination is by wind, and fertilization occurs via a pollen tube (siphonogamy). Seeds are naked, not enclosed in fruits, and often show adaptations like wings for dispersal. Thus, gymnosperms show advanced vegetative adaptations for survival in dry habitats and distinct reproductive features with naked seeds.

Multiple Choice Question (MCQs):

1. Which type of root is common in gymnosperms?
 - a) Fibrous root
 - b) Tap root
 - c) Adventitious root
 - d) Stilt root

Ans: b) Tap root
2. In *Cycas*, coralloid roots are associated with:
 - a) Fungi
 - b) Cyanobacteria
 - c) Algae



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d) Bacteria only

Ans: b) Cyanobacteria

3. Male reproductive organs of gymnosperms are arranged in:

a) Flowers

b) Cones

c) Fruits

d) Capsules

Ans: b) Cones

4. Gymnosperm seeds are called naked because:

a) They lack an embryo

b) They are not enclosed in fruit

c) They are shed early

d) They lack seed coat

Ans: b) They are not enclosed in fruit

5. Which of the following has needle-like leaves as an adaptation to xeric conditions?

a) Cycas

b) Pinus

c) Ginkgo

d) Gnetum

Ans: b) Pinus

Short Answer Questions

1. Why are gymnosperms called “naked-seeded plants”?
2. Write two differences between male and female cones of gymnosperms.
3. Name two types of leaves in gymnosperms with examples.
4. What is the role of coralloid roots in *Cycas*?
5. Mention two xerophytic adaptations of gymnosperm leaves.
6. Define heterospory in gymnosperms with examples.

Long Answer Questions



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1. Describe the vegetative morphology of gymnosperms with suitable examples.
2. Explain the reproductive structures of gymnosperms in detail.
3. Discuss the adaptations of gymnosperm leaves to dry conditions.
4. Compare the male and female cones of gymnosperms with diagrams.
5. Write an essay on the morphology of vegetative and reproductive parts of *Cycas* or *Pinus*.



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UNIT 2.2

Morphology of vegetative and reproduction in pinus

Pinus, commonly known as pine, is a genus of coniferous evergreen trees belonging to the family Pinaceae. These trees are gymnosperms, characterized by their naked seeds, and represent one of the most economically and ecologically significant plant genera on Earth. Pines are widely distributed across the Northern Hemisphere, ranging from tropical to subarctic regions, and have been introduced to various parts of the Southern Hemisphere for timber production and ornamental purposes. The genus encompasses approximately 126 species, each with distinct morphological characteristics adapted to their respective habitats. This comprehensive exploration delves into the intricate morphology of both vegetative and reproductive structures in *Pinus*, elucidating their life cycle and highlighting their profound economic and cultural significance across diverse human societies.

2.2.1 Morphology and Anatomy of Vegetative Structures in Pinus

2.2.1.1 Morphology of Vegetative Structures

Habit and Plant Body: *Pinus* trees are tall, straight, and evergreen. The plant body is differentiated into **roots**, **stems**, and **leaves**. Secondary growth is well developed, giving rise to a thick, woody trunk.

Root System:

- *Pinus* possesses a **taproot system** with numerous lateral branches.
- Young roots show root hairs and mycorrhizal associations with fungi, which help in water and mineral absorption, especially in poor soils.
- Adventitious roots are generally absent.

Stem:

- The main stem is **woody, erect, cylindrical**, and covered with a rough, scaly bark.
- Branching is whorled, producing a conical crown.
- Two kinds of shoots occur:
 - **Long shoots (shoots of unlimited growth):** Bear scale leaves and extend the axis.

- **Dwarf shoots (shoots of limited growth):** Arise in the axils of scales and bear needle-like foliage leaves.

Leaves:

- Two types of leaves are present:
 - **Scale leaves:** Small, thin, membranous, brownish, on the long shoots; protective in function.
 - **Foliage leaves:** Needle-like, green, borne in clusters called **fascicles** on dwarf shoots; commonly 2, 3, or 5 needles per fascicle depending on species.
- These needle leaves are **xeromorphic**, adapted to reduce transpiration in dry, cold habitats.

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Fig. 2.1 Morphology of Vegetative Structures in Pinus

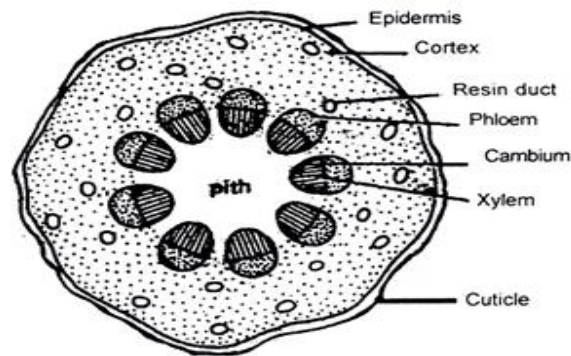
2.2.1.2 Anatomy of Vegetative Structures

Anatomy of Root (Young Root):

- **Epidermis:** Single layer of thin-walled cells with root hairs.
- **Cortex:** Made of parenchyma with mycorrhizal fungal hyphae.
- **Endodermis:** With Casparian strips.
- **Pericycle:** Gives rise to lateral roots.
- **Stele:** Diarch or polyarch xylem with alternating phloem; xylem is composed of tracheids with bordered pits.



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Outline diagram of T.S. of pinus young stem

Fig.2.2 Young Root

Anatomy of Stem (Young Stem):

- **Epidermis:** Thin cuticle with protective layer.
- **Cortex:** Consists of parenchyma and resin ducts lined by secretory epithelial cells.
- **Endodermis and Pericycle:** Not distinct.
- **Vascular Bundles:** Collateral, open type arranged in a ring; xylem of tracheids and phloem of sieve cells and albuminous cells.
- **Pith:** Central parenchyma with resin canals.
- **Secondary Growth:** Active cambium forms annual rings, producing wood (secondary xylem) and secondary phloem. Wood is **pycnoxylic**, mainly tracheids with bordered pits.

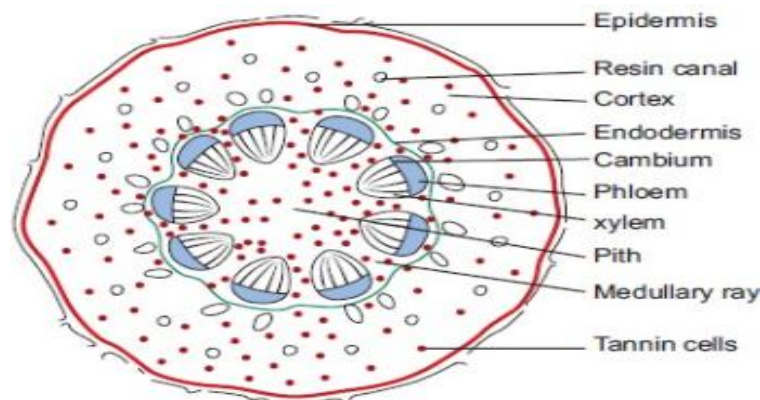


Fig.2.3 Young Stem

Anatomy of Needle Leaf (Foliage Leaf):

- **Epidermis:** Thick cuticle with sunken stomata (xerophytic adaptation).

- **Hypodermis:** 1–2 layers of thick-walled sclerenchyma beneath epidermis for mechanical support.
- **Mesophyll:** Uniform, consisting of chlorenchyma (no differentiation into palisade and spongy).
- **Resin Canals:** Present in mesophyll region.
- **Endodermis:** Surrounds vascular tissue.
- **Vascular Bundles:** Usually two in number, collateral and closed, each surrounded by transfusion tissue (tracheids and albuminous cells) aiding lateral transport.

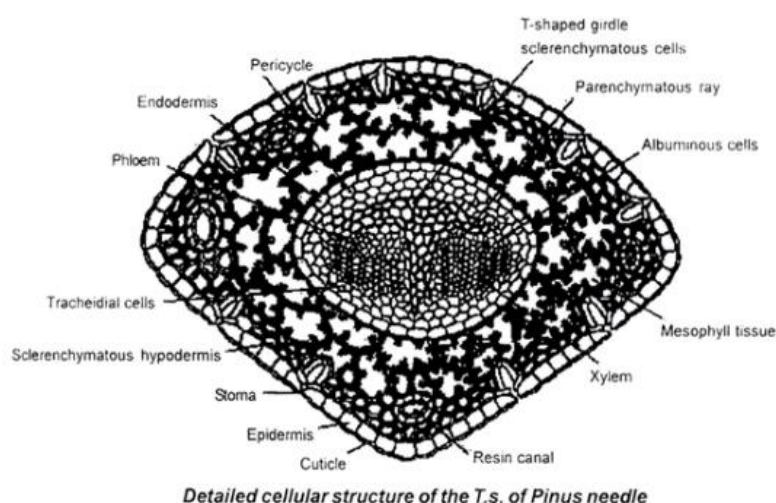


Fig.2.4 Foliage Leaf

2.2.1.3 Reproduction in Pinus: *Pinus* reproduces exclusively by the **sexual method** and, like all gymnosperms, is **heterosporous**, producing two distinct types of spores—microspores (male) and megaspores (female). The plant is **monoecious**, bearing male and female cones on the same individual but on different branches. Male cones are usually borne in clusters on lower branches, while female cones are produced singly or in small groups on upper branches, reducing the chances of self-pollination.

2.2.1.3.1 Male Reproductive Structures (Male Cones)

The male cone, or **microsporangiate strobilus**, is small, cylindrical, and produced in clusters in the axils of scale leaves on long shoots. Each cone bears numerous spirally arranged **microsporophylls**, each bearing two microsporangia on its lower surface. Within the microsporangia, microspore mother cells undergo meiosis to produce **haploid microspores**, which develop into **pollen grains**. The mature pollen grain is a reduced male gametophyte with two characteristic **air sacs (bladders)** that help in wind dispersal.

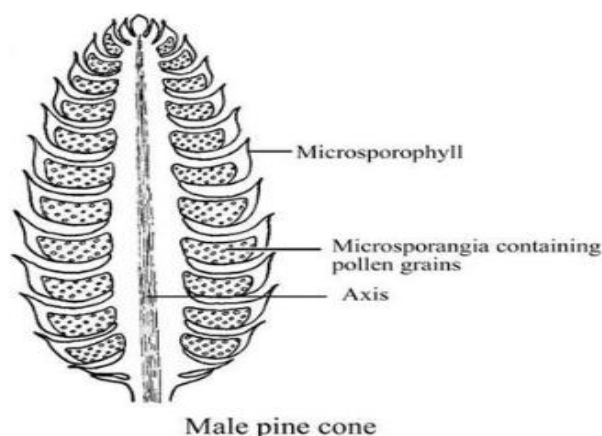


Fig. 2.5 L.S. of pinus female cone

2.2.1.3.2 Female Reproductive Structures (Female Cones)

The female cone, or **megasporangiate strobilus**, is larger and woody. It consists of a central axis bearing spirally arranged **megasporophylls**, each with two ovules on the upper surface. Each ovule consists of a **nucellus** surrounded by an **integument**, leaving a narrow opening called the **micropyle**. Inside the nucellus, a megaspore mother cell undergoes meiosis to produce four megaspores, of which only one survives to form the **female gametophyte**.

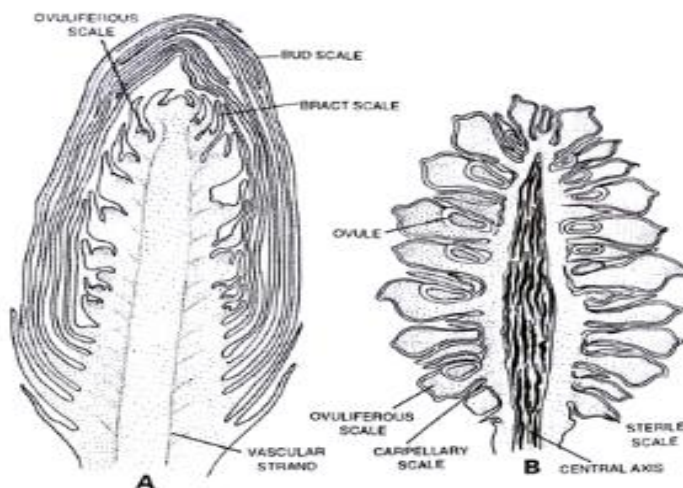


Fig. 2.6 L.S. of pinus female cone

2.2.1.3.3 Pollination and Fertilization

Pinus is **wind-pollinated (anemophilous)**. In spring, vast quantities of pollen are released from the male cones and carried by wind to the micropyle of the ovule in the female cone. The pollen grain rests in a pollen chamber and germinates after a delay, forming a **pollen tube** that slowly grows through the nucellus toward the archegonia. Fertilization is **siphonogamous**, meaning the non-motile male gamete is delivered

through the pollen tube to the egg cell. This process may take over a year, as development in *Pinus* is slow and spread over multiple growing seasons.

Seed Development and Dispersal

After fertilization, the zygote develops into an **embryo** within the ovule. The integuments harden to form a **seed coat**, and the surrounding tissues form stored food (female gametophyte). The mature female cone becomes woody and can take two to three years to ripen fully. When mature, the cone scales open, releasing the **winged seeds**, which are dispersed by wind to new locations. Under favorable conditions, the seed germinates to form a new sporophyte, completing the life cycle.

2.2.1.3.4 Life Cycle of Pinus

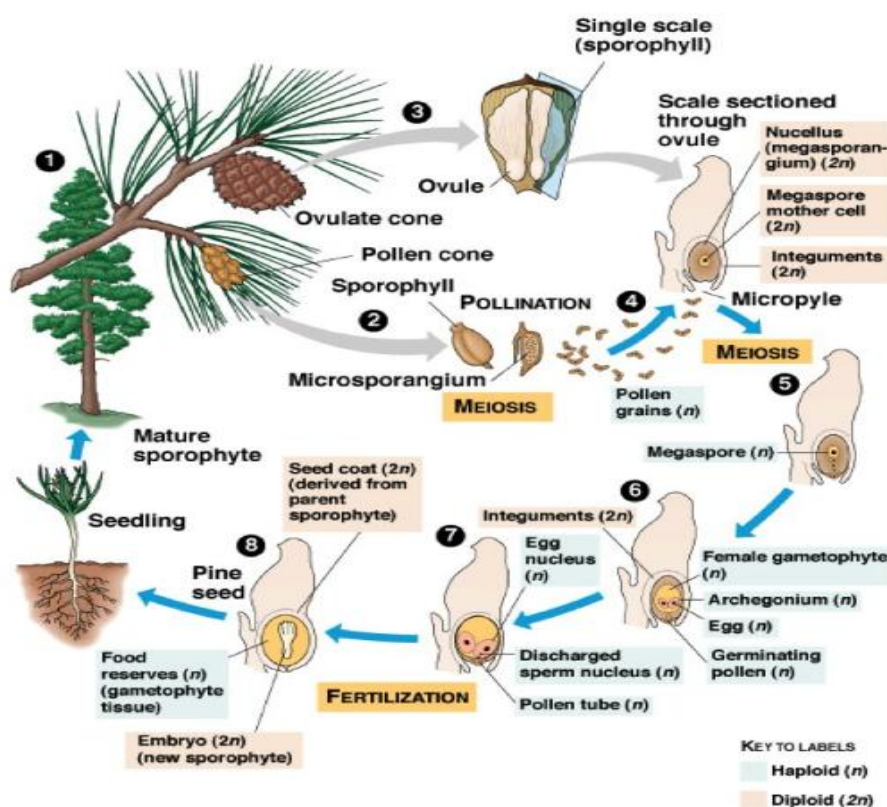


Fig.2.7 life cycle of Pinus

2.2.1.3.5 Economic and Cultural Importance

Pinus is one of the most valuable genera of gymnosperms, playing a significant role in both the economy and cultural practices of many regions. Economically, *Pinus* species are among the most important sources of **timber and wood products**. Their wood, often referred to as **softwood**, is lightweight, strong, and easy to work with, making it highly desirable for construction, furniture, paper, and match industries. Species like *Pinus roxburghii* (chir pine) and *Pinus wallichiana* (blue



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pine) are extensively harvested for commercial timber. The wood pulp of *Pinus* is used in manufacturing paper and rayon, while its resin and oleoresin are tapped to produce **turpentine and rosin**, which are essential in varnishes, paints, adhesives, soaps, and pharmaceutical products. Pine seeds, known as **pine nuts** in some species (*Pinus gerardiana*), are edible and form a nutritious food source rich in oils and proteins.

Culturally, *Pinus* trees have been valued for centuries in many societies. Their tall, evergreen presence is often associated with **longevity, resilience, and fertility**. In several Asian cultures, pines are planted near temples, gardens, and sacred places, symbolizing steadfastness and peace. Pine cones and needles are used in traditional crafts, decorations, and even in festivals or rituals as symbols of prosperity and continuity. In colder regions, pine branches are used for fuel and as a source of aromatic smoke during certain ceremonies. The pleasant fragrance of pine resin has also made it a part of folk medicine, being used in remedies for respiratory ailments and as a natural disinfectant.

Summary:

Pinus is a tall, evergreen, coniferous gymnosperm adapted to cold and dry habitats. It has a well-developed tap root system that forms a symbiotic association with mycorrhizal fungi to aid water and nutrient absorption. The stem is erect, woody, cylindrical, and branched, showing secondary growth and covered by thick bark for protection. Leaves are dimorphic: small scale leaves that are protective and long needle-like foliage leaves arranged in clusters called fascicles. These needle leaves are xerophytic, with thick cuticle, sunken stomata, and hypodermis to prevent water loss. *Pinus* is monoecious, bearing both male and female cones on the same plant. Male cones are small and clustered, each having microsporophylls with microsporangia producing pollen grains, while female cones are larger and woody, bearing ovules exposed on the surface of megasporophylls. Pollination is by wind (anemophilous), and fertilization occurs via a pollen tube (siphonogamy). After fertilization, naked winged seeds are formed, which are dispersed by wind.

Multiple Choice Question (MCQs):

1. The leaves of *Pinus* are arranged in clusters called:
 - a) Whorls



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- b) Fascicles
- c) Strobili
- d) Umbels

Ans: b) Fascicles

2. *Pinus* roots form a symbiotic association with:
- a) Cyanobacteria
 - b) Fungi (mycorrhiza)
 - c) Algae
 - d) Bacteria

Ans: b) Fungi (mycorrhiza)

3. *Pinus* is:
- a) Monoecious
 - b) Dioecious
 - c) Bisexual cones
 - d) Hermaphrodite

Ans: a) Monoecious

4. In *Pinus*, seeds are:
- a) Enclosed in fruit
 - b) Naked and winged
 - c) Without embryo
 - d) With double fertilization

Ans: b) Naked and winged

5. Which type of pollination is found in *Pinus*?
- a) Hydrophily
 - b) Zoophily
 - c) Anemophily
 - d) Entomophily

Ans: c) Anemophily

Short Answer Questions

1. Why are *Pinus* leaves called xerophytic?
2. Define fascicle in *Pinus*.
3. Mention the types of leaves in *Pinus*.



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4. What type of association is found in *Pinus* roots?
5. Differentiate between male and female cones of *Pinus*.
6. Why are *Pinus* seeds called naked seeds?

Long Answer Questions

1. Describe the vegetative morphology of *Pinus* with labeled diagrams.
2. Explain the reproductive structures (male and female cones) of *Pinus*.
3. Discuss the xerophytic adaptations of *Pinus* leaves.
4. Trace the development of male and female gametophytes in *Pinus*.
5. Write an essay on the morphology and life cycle of *Pinus*.

UNIT 2.3

Morphology of vegetative and reproduction in Cycas



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2.3.1 Root System: Cycas root system has only two types of roots; primary roots and coralloid roots. The main taproot is thick, fleshy, and extends directly downwards from the base of the stem, dividing into many secondary and tertiary roots that run horizontally through the soil. These roots anchor the plant and absorb water and nutrients. The most important thing unique to Cycas roots are the coralloid roots. These roots form as offshoots on the lateral branches of primary roots. These coralloid roots grow toward the surface of the soil and often slight above ground. The term "coralloid" comes from their coralliform structure (meaning they have a dichotomous branching pattern). Lenticels around the outer surface of coralloid roots help in gas exchange. The vascular tissues of a normal Cycas root are arranged diarch to polyarch. The outer side of the root consists of epidermis, then a broad cortex. The cortex can be differentiated further into three zones: the outer cortex containing tannin cells; the middle cortex with starch-loaded storage parenchyma cells; and the inner cortex with packed parenchyma cells. In coralloid roots, the cyanobacterial symbionts (usually Nitrogen-fixing Nostoc or Anabaena) inhabit the middle cortical zone (Komaki et al., 2018), where they stay in specialized chambers, living symbiotically with their plant host, providing them with fixed nitrogen from the atmosphere at the cost of housing and carbohydrates. The vascular cylinder is surrounded by an endodermis with Casparian strips. The pericycle is a few cell layers thick and positioned just within of the endodermis. The xylem is arranged in a star shape and the phloem is between the xylem rays. Older roots have a well-developed pith.

2.3.2 Stem Structure Cycas stem is usually unbranched, erect, columnar, and armored with persistent leaf bases. The young plant has a tuberous stem that elongates and becomes cylindrical with age. The most mature specimens have a stem that can measure in 2-10 meters height depending on the species and a diameter of 30-80 cm. The stem terminus is engulfed in a whorl of leaves, providing Cycas with its quintessential palm-like look. On the stem surface, native rhomboidal leaf scars persist marginally in a spirally arranged disposition from the fallen old leaves. The stem between the leaf scars bears a persistent woolly indumentum of multicellular hairs orramenta.

Anatomically, the Cycas stem shows a unique monoxyle structure characterized by a wide cortex and pith with relatively little wood. The stem displays the following tissue organization from outside to inside:

1. A thick periderm forms the outer protective layer of mature stems, replacing the epidermis as the stem grows in diameter.



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2. The cortex is extensive and consists primarily of parenchyma cells rich in starch. Scattered throughout the cortex are mucilage canals, tannin cells, and idioblasts containing calcium oxalate crystals. The cortex also contains leaf traces that curve outward toward the leaf bases.
3. The vascular cylinder consists of a ring of collateral vascular bundles separated by wide medullary rays. The vascular bundles are organized in a complex pattern, with the xylem facing the pith and the phloem facing the cortex. Unlike most gymnosperms, *Cycas* exhibits a distinct cambium that produces secondary xylem and phloem, although secondary growth is relatively slow.
4. The xylem consists of tracheids with bordered pits arranged in an alternating pattern on their walls. The phloem contains sieve cells, albuminous cells, and phloem parenchyma.
5. The pith is expansive and composed of parenchyma cells that store starch. Mucilage canals and tannin cells are also present in the pith.

A unique feature of *Cycas* stems is the presence of girdling leaf traces. As leaf traces depart from the vascular cylinder, they ascend through the cortex for some distance before curving outward to enter the leaf bases. This arrangement results in a complex network of vascular bundles in the cortex.

2.3.3 Leaf Structure: The leaves of *Cycas*, known as fronds, are large, pinnately compound, and arranged in a crown at the apex of the stem. Depending on the species, mature leaves can reach 1-3 meters in length. The leaves are produced in flushes or crowns, with all leaves of a flush emerging simultaneously. Each leaf consists of a petiole and a rachis bearing numerous leaflets (pinnae). The petiole is the basal portion of the leaf that attaches to the stem. It is stout, somewhat flattened on the upper side, and often bears small, sharp spines along the margins. The rachis continues from the petiole and bears the leaflets. The leaflets are linear-lanceolate, leathery, and have an entire margin with a prominent midrib. They are arranged in two rows along the rachis, either in a flat plane or at an angle, creating a V-shaped cross-section. Young leaves emerge from the apex in a circinate manner, with the rachis and leaflets tightly coiled, resembling a fern fiddlehead. As the leaf expands, it gradually unfurls to assume its mature form. Young leaves are covered with brown, woolly hairs (ramenta) that provide protection during development.

In some *Cycas* species, the basal leaflets are reduced to spines, creating a transition zone between the spiny petiole and the normal leaflets.



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Anatomically, the *Cycas* leaf displays the following features:

1. The epidermis is composed of thick-walled cells covered with a thick cuticle, an adaptation to reduce water loss. The stomata are sunken and restricted to the lower surface (hypostomatic), another xerophytic adaptation.
2. The mesophyll is differentiated into palisade and spongy parenchyma. The palisade parenchyma consists of elongated, densely packed cells rich in chloroplasts, located beneath the upper epidermis. The spongy parenchyma consists of loosely arranged cells with intercellular spaces, located above the lower epidermis.
3. Vascular bundles run through the mesophyll, with a large central bundle in the midrib and smaller bundles in the leaf lamina. The vascular bundles are collateral, with xylem toward the upper surface and phloem toward the lower surface. Each vascular bundle is surrounded by a bundle sheath of parenchyma cells.
4. A distinctive feature of *Cycas* leaflets is the presence of transfusion tissue adjacent to the vascular bundles. This tissue consists of tracheids and parenchyma cells and facilitates the lateral transport of water and solutes.
5. Sclerenchyma strands are present above and below the midrib vascular bundle, providing mechanical support.
6. Mucilage canals are scattered in the mesophyll, particularly near the vascular bundles.

The leaves of *Cycas* are long-lived, persisting for several years before senescence. As leaves age, they gradually turn yellow and brown, eventually abscising from the stem, leaving characteristic leaf scars.

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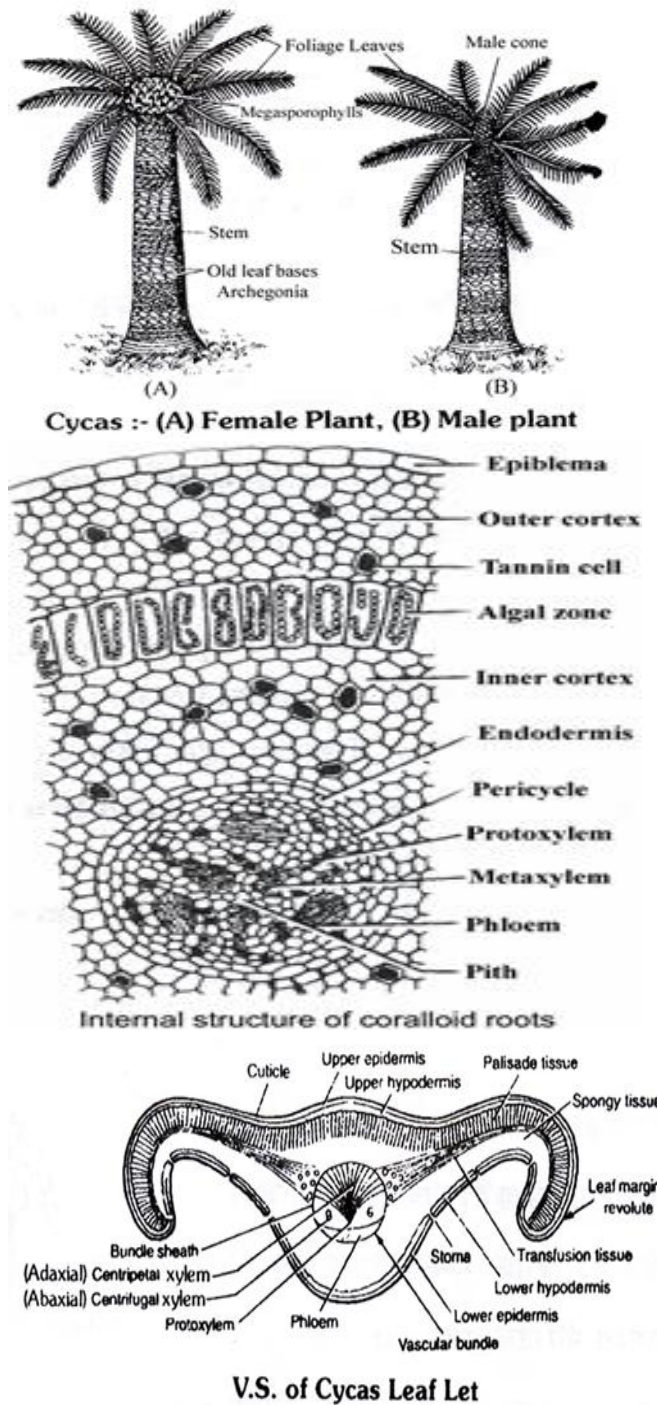


Fig.2.8 Cycas

2.3.4 Reproduction in Cycas

Cycas reproduces both asexually and sexually. Asexual reproduction occurs through the production of bulbils (adventitious buds) that develop on the stem or at the base of the plant. These bulbils can detach and develop into new plants. Some species also produce suckers from the base of the stem. Sexual reproduction in Cycas is complex and



exhibits several primitive features. *Cycas* is dioecious, meaning that male and female reproductive structures develop on separate plants. The reproductive structures are organized into cones or strobili, although the female reproductive structures of *Cycas* are not true cones but rather modified leaves arranged in a crown-like structure.

2.3.4.1 Male Reproductive Structures

The male reproductive structures in *Cycas* form a distinct cone or strobilus at the apex of the stem. The male cone is ovoid to cylindrical in shape, measuring 20-60 cm in length and 10-20 cm in diameter, depending on the species. It consists of numerous spirally arranged microsporophylls attached to a central axis. Each microsporophyll is a modified leaf with a broad, flattened, sterile upper portion and a narrow, fertile lower portion. The sterile portion often ends in a pointed apex and may bear hairs or scales. The fertile portion bears numerous microsporangia (pollen sacs) on its lower surface, arranged in groups called sori. Each microsporangium contains microspores (pollen grains).

Anatomically, a microsporophyll shows the following features:

1. A thick epidermis covered with a cuticle.
2. Ground tissue composed of parenchyma cells with scattered vascular bundles.
3. Microsporangia attached to the abaxial (lower) surface. Each microsporangium has a wall composed of several layers of cells, with the innermost layer differentiating into a tapetum that nourishes the developing microspores.

The development of pollen (microgametogenesis) begins with the microsporocytes (microspore mother cells) undergoing meiosis to produce four haploid microspores. Each microspore develops into a pollen grain through mitotic divisions. The mature pollen grain of *Cycas* is oval-shaped and contains three cells: a tube cell, a generative cell, and a prothallial cell. This three-celled condition is considered primitive among gymnosperms. When mature, the microsporangia dehisce along a longitudinal slit, releasing the pollen grains. Pollination in *Cycas* is anemophilous (wind-pollinated), with pollen grains carried by air currents to female plants.

2.3.4.2 Female Reproductive Structures

The female reproductive structures of *Cycas* differ significantly from those of other gymnosperms. Unlike most gymnosperms, *Cycas* does not produce a compact female cone. Instead, the megasporophylls (seed-bearing leaves) are loosely arranged in a crown at the stem apex, interspersed with sterile leaves. Each megasporophyll is a modified leaf



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with a proximal stalk-like portion and a distal expanded lamina. The lamina is pinnately divided or deeply lobed, resembling a miniature vegetative leaf. The ovules (megasporeangia) are borne on the margins of the stalk-like portion, typically 2-12 in number depending on the species. Each ovule is large (1-5 cm in diameter), ovoid, and orthotropous (straight, with the micropyle facing directly away from the attachment point).

Anatomically, an ovule of *Cycas* shows the following structure from outside to inside:

1. A thick integument with three distinct layers: an outer fleshy layer (sarcotesta), a middle stony layer (sclerotesta), and an inner fleshy layer (endotesta). The integument is perforated at the apex by a micropyle, a narrow canal through which pollen grains enter.
2. A nucellus (megasporeangium) that fills the space inside the integument. The nucellus is attached to the integument at its base but is free from it in the upper portion, creating a pollen chamber just below the micropyle.
3. A megaspore mother cell embedded deep within the nucellus undergoes meiosis to produce four megaspores, of which three degenerate. The surviving megaspore enlarges and develops into the female gametophyte (endosperm) through free nuclear divisions followed by wall formation.

The mature female gametophyte contains numerous cells rich in starch and other food reserves. At the micropylar end, 2-6 archegonia develop, each consisting of a neck and a ventral cell. The ventral cell enlarges to form the egg cell, which is the largest known cell in the plant kingdom, visible to the naked eye.

2.3.4.3 Life Cycle of *Cycas*

The life cycle of *Cycas* illustrates the alternation of generations typical among all land plants, though several of its features are primitive, indicative of its evolutionarily intermediate position. The dominating sporophyte generation is preceded by a greatly reduced gametophyte generation that is completely dependent on the sporophyte.

2.3.4.3.1 Sporophyte Generation

The more familiar, perennial sporophyte generation is the tall, vertical-bodied plant described earlier with its typical unbranched stem, whorl of pinnate leaves (each leaf divided into smaller leaflets) and complex root system. It is diploid (2n) and gives rise to haploid (n) spores from



meiosis. The sporophyte grows and develops specialized reproductive structures: microsporophylls grouped to form male cones on male plants, and megasporophylls loosely packed at the apex of the stem of female plants.

2.3.4.3.2 Microgametophyte Development

Male plants are formed when microsporocytes (microspore mother cells) in the microsporangia of microsporophylls meiotically divide and produce haploid microspores. The pollen grain (representing the immature male gametophyte, or microgametophyte) develops from each microspore. While the pollen grain is still in the microsporangium, the male gametophyte develops. The nucleus of microspore divides mitotically to form prothallial cell, generative cell and tube cell. The three-celled stage of the pollen grain is regarded as primitive among the gymnosperms, and it resembles the multicellular male gametophytes of the non-seed plants. The microsporangia ultimately release mature pollen grains to be transported by wind to female plants. Upon landing on a receptive ovule, a pollen grain is sucked into the pollen chamber via the micropyle, typically aided by a pollination droplet secreted from the ovule. Inside the pollen chamber, the pollen grain will germinate. The tube cell becomes a branched pollen tube that works its way through the nucellus and absorbs nutrients. At the same time, the generative cell divides to produce a stalk cell and a body cell. The body cell then splits and forms two sperm cells, each with many flagella — a characteristic exclusive to Cycadophyta and Ginkgophyta among living seed plants, and which is similar to the flagellated sperm of ferns and other non-seed-producing plants.

2.3.4.3.3 Megagametophyte Development

In female plants, the megaspore mother cell of each ovule undergoes meiosis in the nucellus to form four megaspores, three of which usually degenerate. The megaspore that survives grows in size and develops into the female gametophyte (megagametophyte), which stays inside the nucellus of the ovule. The female gametophyte then undergoes several rounds of mitotic division of the megaspore nucleus without cytokinesis, leading to a multinucleate syncytium. When several nuclei evolve, partitions appear to produce a cellular female gametophyte (also known as primary endosperm). It is the pollen grain, which gives rise to the female gametophyte and enters the cytoplasm of the pollen tube and grows through the ovule structure. Between them, at the micropylar end of the female gametophyte, 2-6 archegonia are formed, each with a single, large egg cell. The archegonium has a brief neck composed of two tiers of cells, as well as a ventral canal cell



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that begins degenerating prior to fertilization, so that the only living cell in the mature archegonium is the egg cell.

2.3.4.3.4 Fertilisation and Embryo Development

Once the pollen grain has germinated inside the pollen chamber, it extends a pollen tube downward through the nucellus and toward the female gametophyte. Here the pollen tube bursts to release two flagellated sperm cells. They then swim up in the back of the cavity, between the nucellus and the female gametophyte, and swim into the archegonia through the archegonial neck cells. In each archegonium, one sperm cell fuses with the egg cell to create a diploid zygote through fertilization. More than one archegonium may be fertilized, resulting in polyembryony, however usually only one embryo matures. The zygote divides by mitosis to form a proembryo, which later differentiates into an embryo proper and a suspensor. Suspensor forces embryo proper into female gametophyte nutritive tissue. The embryo proper develops into a small root (the radicle), stem (the plumule) and usually two cotyledons.

2.3.4.3.5 The Making of the Seed and Seed Germination

The ovule is a fertilized part that we know as a seed. The integument becomes hardened and differentiated into the three previously described layers; sarcotesta, sclerotesta, and endotests. The nucellus is mostly ingressed and absorbed as the embryo develops, leaving a thin layer — the perisperm. The embryo, now inside the female gametophyte, will be the seed's endosperm. The mature seed of *Cycas* is one of the largest seeds in the gymnosperm world, often 2-5 cm diameter. It has a soft outer layer that is usually bright red or orange to attract animals that help in spreading the seeds. In *Cycas*, seed germination is usually hypogeal, as the cotyledons stay underground inside the seed. The first step of germination is the emergence of the radicle, then of the plumule. Initially, the young seedling exploits the energy reserves stored in the endosperm. This stage of development of the young sporophyte is slow, as the first true leaves appear when the seed reserves have been utilized. The first leaves are often simpler than the adult leaves, having fewer and broader leaflets. As the plant grows it grows more and more complex leaves until it gains adult morphology. Because *Cycas* is a slow-growing plant and doesn't begin reproduction until attaining a specific age and size, it can take 15-20 years or longer for the life cycle from spore-stage to spore-stage.

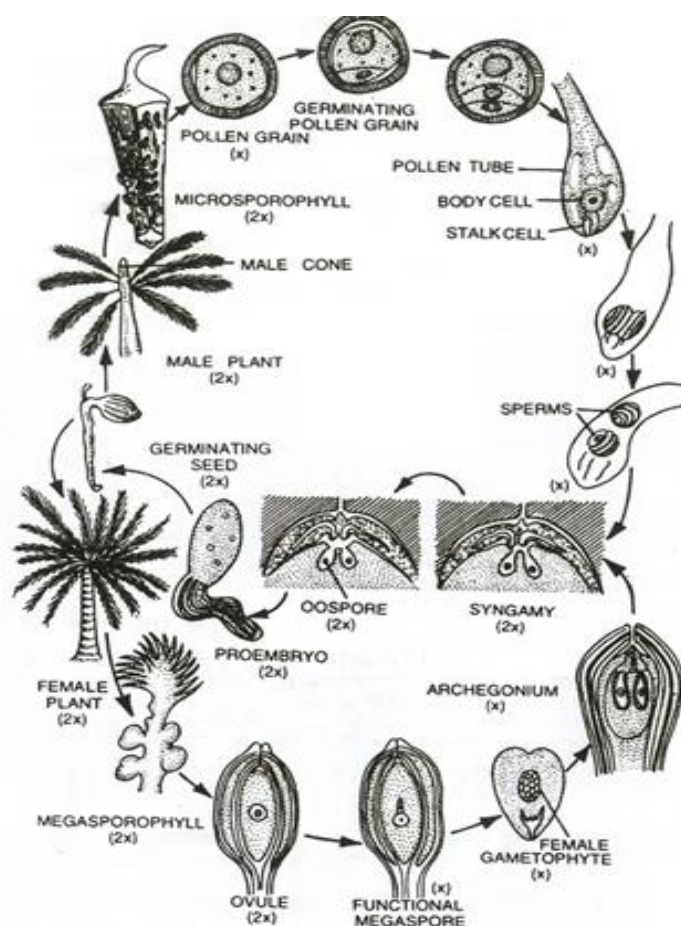


Fig.: Cycas : Alternation of Generation

Fig. 2.9 Cycas

2.3.5 Economic and Cultural Importance

2.3.5.1 Economic Importance

Cycas species have significant economic importance in various regions of the world, particularly in tropical and subtropical Asia, Australia, and the Pacific Islands. Their economic value stems from multiple uses:

- **Food Source:** The stem pith of several Cycas species contains starch that is extracted and processed into "sago," a food staple in parts of Asia and the Pacific. The seeds of some species are also edible after proper processing to remove toxins. In times of famine, Cycas has been an important emergency food source for indigenous communities.
- **Ornamental Plants:** Cycas species, particularly *Cycas revoluta* (Sago Palm) and *Cycas circinalis* (Queen Sago), are highly valued as ornamental plants in tropical and subtropical gardens worldwide. Their distinctive palm-like appearance, with a crown of dark green pinnate leaves, makes them attractive



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landscape elements. They are also popular as container plants for patios, atriums, and indoor spaces with adequate lighting.

- **Horticulture Trade:** The global trade in *Cycas* plants for ornamental purposes represents a significant economic activity. Nurseries specializing in exotic and tropical plants often propagate and sell various *Cycas* species and cultivars. The slow growth rate of *Cycas* makes mature specimens particularly valuable, with large plants commanding high prices in the horticultural market.
- **Traditional Medicine:** Various parts of *Cycas* plants have been used in traditional medicine systems, particularly in Asia. The seeds, leaves, and roots are employed in traditional remedies for ailments ranging from wounds and skin diseases to respiratory conditions and gastrointestinal disorders. However, the medicinal use of *Cycas* requires caution due to the presence of toxins.
- **Source of Biomolecules:** Scientific research has identified various bioactive compounds in *Cycas* plants, including cycasins, MAM glycosides, and biflavonoids, which have potential pharmaceutical applications. These compounds are being studied for their anti-inflammatory, antimicrobial, and anticancer properties.
- **Fiber Production:** The leaves of some *Cycas* species yield fibers that are used in making ropes, baskets, mats, and other woven products in certain traditional communities.

2.3.5.2 Cultural Importance

Beyond their economic value, *Cycas* species hold significant cultural importance in many societies:

- **Religious and Ceremonial Significance:** In various cultures, particularly in Asia and the Pacific, *Cycas* plants hold symbolic and ceremonial importance. In Japan, *Cycas revoluta* (known as "sotetsu") is associated with Buddhist temples and is planted as a symbol of longevity and perseverance. In India, *Cycas circinalis* is considered sacred in some regions and is associated with religious ceremonies.
- **Symbolic Value:** The resilience and longevity of *Cycas* plants have made them symbols of endurance and steadfastness in various cultural contexts. Their ability to survive in harsh conditions and their ancient lineage contribute to their symbolic significance.



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- **Traditional Customs and Rituals:** In some Pacific Island cultures, Cycas leaves are used in traditional ceremonies and rituals, including coming-of-age ceremonies, funeral rites, and community celebrations. The plants may mark sacred spaces or be incorporated into ceremonial structures.
- **Historical Significance:** In parts of Asia, particularly Japan and the Ryukyu Islands, Cycas has historical significance as a famine food that saved populations during periods of crop failure and food scarcity. This historical role has embedded Cycas in cultural memory and folklore.
- **Indigenous Knowledge:** Traditional ecological knowledge about Cycas, including methods of detoxifying the seeds for consumption, harvesting techniques that preserve the plants, and sustainable management practices, represents an important cultural heritage for many indigenous communities.

Summary:

Cycas is a primitive gymnosperm and resembles palms in appearance. It is a slow-growing, evergreen plant that mainly occurs in tropical and subtropical regions. The plant body is sporophytic and differentiated into root, stem, and leaves. The root system is tap-rooted, with normal roots growing deep in soil for absorption and specialized **coralloid roots** that grow near the soil surface, are greenish, and contain symbiotic cyanobacteria (*Anabaena*, *Nostoc*) for nitrogen fixation. The stem is unbranched, woody, columnar, and covered with persistent leaf bases and scaly leaves.

Leaves are dimorphic: **scaly leaves** (brown, protective, produced in clusters) and **green pinnate foliage leaves** (large, compound, leathery, and spirally arranged at the stem apex). Young leaves show circinate vernation.

Multiple Choice Question(MCQs):

1. *Cycas* roots with symbiotic cyanobacteria are called:
 - a) Tap roots
 - b) Fibrous roots
 - c) Coralloid roots
 - d) Adventitious roots

Ans: c) Coralloid roots



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2. *Cycas* is:
- a) Monoecious
 - b) Dioecious
 - c) Bisexual
 - d) Hermaphrodite

Ans: b) Dioecious

3. The type of vernation in *Cycas* leaves is:
- a) Convolute
 - b) Circinate
 - c) Straight
 - d) Imbricate

Ans: b) Circinate

4. Which of the following is absent in *Cycas*?
- a) Archegonia
 - b) Male cone in female plant
 - c) Pollen grains
 - d) Embryo in seed

Ans: b) Male cone in female plant

5. Male gametes of *Cycas* are:
- a) Non-motile
 - b) Biflagellate
 - c) Ciliated and motile
 - d) Amoeboid

Ans: c) Ciliated and motile

Short Answer Questions

- 1. What are coralloid roots and their function in *Cycas*?
- 2. Distinguish between foliage and scale leaves of *Cycas*.
- 3. Mention one primitive character found in *Cycas* male gametes.
- 4. What type of plant is *Cycas* in terms of sexuality?
- 5. Why are *Cycas* leaves considered xerophytic?
- 6. What is circinate vernation?

Long Answer Questions

1. Describe the vegetative morphology of *Cycas* with diagrams.
2. Explain the reproductive structures of *Cycas* and how they differ in male and female plants.
3. Discuss the role and structure of coralloid roots in *Cycas*.
4. Trace the development of male and female gametophytes in *Cycas*.
5. Write an essay on the morphology and life cycle of *Cycas*.



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UNIT 2.4

Morphology of vegetative and reproduction in *Ephedra*

Ephedra, also called Ma Huang, joint fir, or Mormon tea, genus of gymnospermous shrubs in the family Ephedraceae and order Gnetales. These xerophytes are widespread in arid and semi-arid zones of both hemispheres, extending from western North America to South America, parts of Europe, northern Africa, and central Asia. This genus of Gnetophytes is significant as there are only two other living genera: *Gnetum* and *Welwitschia*, making it an important subject in evolutionary lineage of seed plants. There are ~60–70 species primarily in the genus *Ephedra*, where *Ephedra distachya*, *Ephedra sinica*, and *Ephedra nevadensis* are most commonly studied. The vegetative and reproductive structures, life cycle, economic and cultural importance of *Ephedra* are handled in this chapter.

2.4.1 Morphology and Anatomy of vegetative in *Ephedra*

2.4.1.1 External Morphology

Ephedra is a gymnosperm belonging to the order **Gnetales**. It is a small shrub or climber found mostly in dry, xerophytic habitats such as sandy soils and semi-deserts. The plant body is differentiated into **root, stem, and leaves** with clear xerophytic adaptations. The **root system** is typically a deep taproot with lateral branches, enabling the plant to absorb water from deeper soil layers. The **stem** is green, slender, and jointed, with conspicuous nodes and internodes. It is photosynthetic, as the leaves are reduced. The stems are ribbed, and branches arise in whorls from the nodes. The **leaves** are small, scaly, and opposite or in whorls, fused at the base to form a sheath around each node. These reduced leaves help minimize water loss, while the stem takes over the photosynthetic function.



Figure: 2.10 Morphology of *Ephedra*

2.4.1.2 Anatomy of Root:

The young root shows a typical gymnosperm structure. The outer **epidermis (piliferous layer)** bears root hairs. The **cortex** is made of thin-walled parenchyma storing food. The **stele** is diarch or triarch, with radial arrangement of xylem and phloem. Secondary growth occurs through the activity of vascular cambium, producing secondary xylem and phloem, giving rise to a woody root.

2.4.1.2.1 Anatomy of Stem: A transverse section of a young stem of *Ephedra* shows a thin **epidermis** covered with a thick cuticle, helping in water conservation. Beneath it lies a layer of **collenchyma** giving mechanical strength, followed by a **cortex** made of chlorenchyma with resin canals. The **vascular bundles** are arranged in a ring and are **collateral and open**, with a well-developed cambium layer between xylem and phloem, allowing secondary growth. The **xylem** consists of both tracheids and vessels (a feature unique among gymnosperms and resembling angiosperms), while the **phloem** has sieve cells and companion-like albuminous cells. The central region is occupied by a **parenchymatous pith**.

1. **Epidermis:** The outermost layer consists of compactly arranged epidermal cells covered by a thick cuticle. Stomata are sunken and arranged in rows along the stem grooves, reducing water loss.
2. **Cortex:** Beneath the epidermis lies the cortex, which can be divided into two zones:



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- Outer cortex (hypodermis): Consists of 2-4 layers of sclerenchymatous cells providing mechanical support.
- Inner cortex: Composed of chlorenchymatous cells arranged radially around substomatal chambers, forming the main photosynthetic tissue of the plant.

3. **Vascular Tissue:** The vascular bundles are arranged in a ring at the junction of the cortex and pith. Each bundle is collateral, with xylem toward the center and phloem toward the periphery. The xylem consists primarily of tracheids with bordered pits, while vessels occur in some species, representing an advanced feature among gymnosperms. The phloem contains sieve cells and parenchyma.
4. **Pith:** The center of the stem contains parenchymatous pith cells, which may become hollow in older stems due to the disintegration of pith cells.

2.4.1.2.2 Leaves

The leaves of Ephedra represent one of the most reduced forms among seed plants, reflecting an extreme adaptation to minimize water loss in arid environments. The leaves are small, scale-like structures arranged in opposite or whorled patterns at the nodes. They measure approximately 2-8 mm in length and are typically connate (fused) at the base to form a sheath around the node.

Anatomically, the leaf is relatively simple in structure:

1. **Epidermis:** Both adaxial and abaxial surfaces are covered by epidermal cells with thick cuticles.
2. **Mesophyll:** The mesophyll is poorly differentiated and consists primarily of a few layers of parenchymatous cells, which may contain chloroplasts in young leaves.
3. **Vascular Tissue:** A single, small vascular bundle runs through the center of the leaf, consisting of a few xylem and phloem elements.
4. **Sclerenchyma:** Strands of sclerenchymatous fibers provide mechanical support and contribute to the rigidity of the leaf.

The extreme reduction of leaves in Ephedra represents an evolutionary response to arid conditions, minimizing the surface area available for transpiration. The photosynthetic function has been largely transferred to the green stems, which have a lower surface area to volume ratio and therefore lose less water per unit of photosynthetic tissue.



2.4.3 Reproduction in Ephedra

2.4.3.1 Reproductive Structures

Ephedra is predominantly dioecious, meaning male and female reproductive structures develop on separate plants, though rare monoecious individuals have been reported in some species. The reproductive structures are arranged in compact strobili (cones) that develop at the nodes of stems.

2.4.3.1.1 Male Reproductive Structures: The male reproductive units are organized into compound strobili, often called male cones or microsporangiate strobili. These strobili typically measure 3-8 mm in length and occur singly or in clusters at the nodes. Each male strobilus consists of several pairs of bracts (modified leaves) arranged decussately (in opposite pairs at right angles to each other). The bracts are fused at their bases to form short, cup-like structures. Within the axils of the uppermost bracts, microsporangiphores (structures bearing microsporangia) develop. Each microsporangiphore consists of a slender stalk that extends beyond the bracts and terminates in a cluster of 2-8 microsporangia (pollen sacs). The microsporangia are protected by the surrounding bracts during development.

Anatomically, each microsporangium has a wall composed of several layers:

1. **Epidermis:** The outermost protective layer
2. **Endothecium:** A layer of cells with fibrous thickenings that assist in dehiscence
3. **Middle Layers:** 1-2 layers of cells that degenerate during development
4. **Tapetum:** The innermost nutritive layer that provides nutrients to the developing microspores

Inside the microsporangia, microspore mother cells undergo meiosis to produce haploid microspores, which develop into mature pollen grains (male gametophytes). The mature pollen grain in Ephedra is ellipsoidal to spherical and features longitudinal furrows or ridges on its surface. It possesses a thick exine (outer wall) and a thin intine (inner wall). A unique feature of Ephedra pollen is the presence of multiple longitudinal ridges or furrows (5-13, depending on the species), which distinguish it from other gymnosperm pollen.

When mature, the microsporangia dehisce longitudinally, releasing the pollen grains, which are then dispersed by wind to reach female cones.



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2.4.3.1.2 Female Reproductive Structures

The female reproductive units, known as ovulate strobili or female cones, are structurally more complex than their male counterparts. These strobili measure approximately 5-15 mm in length and typically develop singly or in pairs at the nodes. Each female strobilus consists of several pairs of decussately arranged bracts that are partially fused at their bases.

In the axil of the uppermost pair of bracts, one or occasionally two ovules develop. Each ovule is orthotropous (straight) and unitegmic (having a single integument). The integument extends beyond the nucellus (megasporeangium) to form a long, tubular structure called the micropylar tube, which protrudes beyond the bracts. The micropylar tube secretes a pollination droplet that captures airborne pollen grains during pollination.

The ovule consists of the following parts:

1. **Integument:** A single, thick protective layer that surrounds the nucellus and extends to form the micropylar tube
2. **Nucellus:** The central tissue containing the megaspore mother cell
3. **Vascular Supply:** Vascular traces extend into the base of the ovule

A unique feature of *Ephedra* ovules is the presence of a distinct pollination chamber at the apex of the nucellus, which receives the pollen grains after they are drawn down through the micropylar tube.

2.4.4 Gametophyte Development

2.4.4.1 Male Gametophyte (Pollen Grain) Development

The development of the male gametophyte begins with the microspore mother cells ($2n$) within the microsporangium undergoing meiosis to produce four haploid microspores. Each microspore then undergoes a series of mitotic divisions to form the mature male gametophyte (pollen grain).

In *Ephedra*, the mature pollen grain at the time of dispersal typically contains three cells:

1. **Prothallial Cell:** A sterile cell representing the vegetative tissue of the male gametophyte
2. **Antheridial Cell:** Divides to form a sterile cell and a generative cell



3. **Tube Cell:** Forms the pollen tube during fertilization

After the pollen grain lands on the pollination droplet of a female cone, it is drawn into the micropylar tube. The pollen grain germinates, and the tube cell elongates to form a branched pollen tube that grows through the nucellus toward the female gametophyte. Meanwhile, the generative cell divides to form two sperm cells, which are unique among gymnosperms for being multiflagellated (possessing multiple flagella), a character shared with other Gnetales.

2.4.4.2 Female Gametophyte Development

The development of the female gametophyte begins with a single megaspore mother cell ($2n$) in the nucellus undergoing meiosis to produce four haploid megaspores. Typically, three of these megaspores degenerate, while the remaining functional megaspore enlarges and undergoes free-nuclear divisions without cytokinesis, forming a multinucleate coenocyte.

Cell walls eventually form around these nuclei, creating a cellular female gametophyte (endosperm). At the micropylar end of the female gametophyte, two or more archegonia develop, each containing a large egg cell. A distinctive feature of *Ephedra* is the formation of archegonial chambers, which are depressions in the female gametophyte that house the archegonia.

2.4.4.3 Pollination and Fertilization

Pollination in *Ephedra* is anemophilous (wind-mediated), facilitated by the production of large quantities of lightweight pollen. When released from the microsporangia, pollen grains are carried by air currents and may land on the micropylar tubes of female cones, where they adhere to the pollination droplet.

The pollination droplet, a viscous fluid exuded from the micropylar tube, serves multiple functions:

1. It captures airborne pollen grains
2. It provides a medium for pollen hydration
3. As the droplet retracts due to evaporation or reabsorption, it draws the pollen grains into the micropylar tube

Once inside the micropylar tube, the pollen grain germinates, producing a pollen tube that grows through the nucellus toward the archegonia. The pollen tube may branch extensively within the nucellus, a characteristic feature of *Ephedra*. The generative cell divides to form two sperm cells, each with multiple flagella.



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When the pollen tube reaches an archegonium, it ruptures, releasing the sperm cells. One sperm cell fertilizes the egg cell, forming a diploid zygote, while the other sperm cell degenerates. Unlike many other gymnosperms, double fertilization has been reported in some *Ephedra* species, where the second sperm cell fuses with another nucleus in the female gametophyte, although this second fusion product typically degenerates without developing further.

2.4.4.4 Embryo and Seed Development

Following fertilization, the zygote undergoes mitotic divisions to form a proembryo. The early development of the embryo in *Ephedra* shows some unique features:

1. **Free-nuclear Stage:** The zygote initially undergoes several mitotic divisions without cytokinesis, forming a multinucleate structure.
2. **Cellular Proembryo:** Cell walls form around the nuclei, creating a cellular proembryo.
3. **Suspensor Development:** Cells at the upper end of the proembryo elongate to form a suspensor, which pushes the developing embryo deeper into the nutritive tissue of the female gametophyte.
4. **Embryo Proper:** The cells at the lower end of the proembryo develop into the embryo proper, which differentiates to form the following structures:
 - **Radicle:** The embryonic root, positioned toward the micropylar end
 - **Hypocotyl:** The region between the radicle and cotyledons
 - **Plumule:** The embryonic shoot apex
 - **Cotyledons:** Two in number, forming the first seed leaves

As the embryo develops, the female gametophyte accumulates storage materials (primarily starch, proteins, and lipids) and functions as nutritive tissue analogous to the endosperm in angiosperms.

The integument of the ovule hardens to form the seed coat, while the bracts surrounding the ovule become fleshy or leathery, often taking on a reddish or yellowish color at maturity. The mature seed of *Ephedra* is relatively small (typically 5-10 mm in length) and is partially enclosed by the modified bracts, which may aid in dispersal by animals attracted to the colorful, sometimes fleshy structures.



2.4.4.5 Life Cycle of Ephedra

The life cycle of Ephedra, like other seed plants, alternates between a dominant diploid sporophyte generation and a reduced haploid gametophyte generation. The cycle begins with the mature sporophyte plant and proceeds through various stages of reproduction, culminating in the formation of a new sporophyte generation.

2.4.4.5.1 Sporophyte Phase

1. **Mature Sporophyte:** The visible Ephedra plant represents the diploid ($2n$) sporophyte generation. It consists of roots, stems, reduced leaves, and reproductive structures.
2. **Reproductive Structure Formation:** The mature sporophyte develops specialized reproductive structures—male strobili on male plants and female strobili on female plants (as Ephedra is primarily dioecious).
3. **Sporogenesis:** Within these reproductive structures, specialized cells undergo meiosis to produce haploid spores:
 - In male strobili, microspore mother cells undergo meiosis to form haploid microspores.
 - In female strobili, a megaspore mother cell undergoes meiosis to form four haploid megaspores, typically with only one surviving.

2.4.4.5.2 Gametophyte Phase

1. **Male Gametophyte Development:** Each microspore develops into a male gametophyte (pollen grain) through mitotic divisions. The mature pollen grain contains a prothallial cell, an antheridial cell, and a tube cell.
2. **Female Gametophyte Development:** The functional megaspore undergoes free-nuclear divisions followed by cellularization to form the female gametophyte (endosperm). Archegonia, each containing an egg cell, develop at the micropylar end of the female gametophyte.

2.4.4.5.3 Pollination and Fertilization

1. **Pollination:** Wind carries pollen grains to the micropylar tubes of female cones, where they adhere to pollination droplets and are drawn into the micropylar canal.



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2. **Pollen Germination:** Inside the micropylar canal, the pollen grain germinates, forming a pollen tube that grows through the nucellus toward the archegonia.
3. **Sperm Cell Formation:** The generative cell within the pollen grain divides to form two multiflagellated sperm cells.
4. **Fertilization:** When the pollen tube reaches an archegonium, it ruptures, releasing the sperm cells. One sperm cell fertilizes the egg cell, forming a diploid (2n) zygote.

2.4.4.5.4 Embryo and Seed Development

1. **Embryogenesis:** The zygote undergoes mitotic divisions to form an embryo, which develops a radicle, hypocotyl, plumule, and two cotyledons.
2. **Seed Formation:** The female gametophyte accumulates storage materials, the integument hardens to form the seed coat, and the surrounding bracts become modified, often becoming fleshy or colorful.
3. **Seed Dispersal:** Mature seeds are dispersed, primarily by wind or animals attracted to the modified bracts.

2.4.4.5.5 Germination and Establishment

1. **Seed Germination:** Under favorable conditions, the seed germinates. The radicle emerges first, developing into the primary root, followed by the emergence of the hypocotyl and cotyledons.
2. **Seedling Establishment:** The seedling establishes itself, developing into a juvenile plant with photosynthetic stems and reduced leaves.
3. **Maturation:** Over several years, the juvenile plant grows and matures into an adult sporophyte capable of reproduction, thus completing the life cycle.

The life cycle of Ephedra exhibits several distinctive features compared to other gymnosperms:

- The presence of vessels in the xylem of some species (an angiosperm-like feature)
- Multiflagellated sperm cells (a primitive feature shared with ferns and some other gymnosperms)
- The formation of a pollination droplet to capture pollen
- Reports of a form of double fertilization in some species (typically associated with angiosperms)

- The development of fleshy, colorful structures surrounding the seeds, facilitating animal dispersal

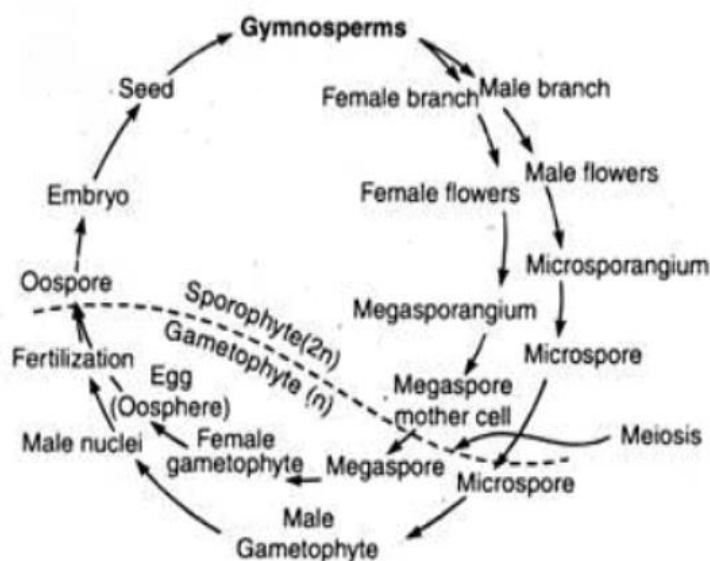


Fig. 2.11 Graphical life cycle of ephedra

2.4.5 Economic and Cultural Importance

2.4.5.1 Medicinal Applications

Ephedra has a long and significant history of medicinal use across various cultures, primarily due to the presence of alkaloids, particularly ephedrine and pseudoephedrine. These compounds have sympathomimetic properties, meaning they mimic the effects of the sympathetic nervous system.

1. **Traditional Chinese Medicine:** Ephedra sinica (known as "Ma Huang") has been used in Chinese medicine for over 5,000 years to treat asthma, bronchitis, and other respiratory conditions. The earliest documented medicinal use appears in the Shen Nong Ben Cao Jing (Divine Farmer's Materia Medica), dating to approximately 2700 BCE.
2. **Western Medicine:** Ephedrine was isolated from Ephedra in 1887 by the Japanese chemist Nagai Nagayoshi, and it subsequently gained importance in Western medicine as:
 - A bronchodilator for treating asthma and allergic reactions
 - A nasal decongestant
 - A cardiac stimulant



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- A treatment for hypotension (low blood pressure)

3. **Modern Pharmaceutical Uses:** Pseudoephedrine, a stereoisomer of ephedrine, is widely used in over-the-counter decongestant medications. However, due to its potential conversion into methamphetamine, its sale is now restricted or controlled in many countries.
4. **Regulatory Status:** Concerns about adverse effects led to significant restrictions on ephedra-containing dietary supplements in many countries. In 2004, the U.S. Food and Drug Administration banned the sale of dietary supplements containing ephedrine alkaloids due to associated cardiovascular risks.

Summary

Various indigenous communities, particularly in North America and Central Asia, have utilized Ephedra species for medicinal, nutritional, and ceremonial purposes:

1. **Native American Uses:** Several Native American tribes, including the Navajo, Hopi, and Shoshone, used species such as *Ephedra nevadensis* and *Ephedra viridis* (commonly known as "Mormon tea" or "Indian tea") to prepare beverages that served both medicinal and nutritional purposes. These were used to treat:
 - Urinary tract infections
 - Venereal diseases
 - Kidney disorders
 - Cold and flu symptoms
2. **Central Asian Traditional Uses:** In regions of Central Asia, local communities have traditionally used Ephedra to treat respiratory conditions, rheumatism, and fever.
3. **Beverage Preparation:** Stems are typically dried and then steeped in hot water to prepare tea-like beverages. These decoctions were valued for their stimulant properties and ability to suppress appetite during food scarcity.

SELF ASSESSMENT QUESTIONS

Multiple Choice Questions (MCQs):

1. Which of the following is NOT a characteristic of gymnosperms?
a) Naked seeds



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- b) Presence of flowers
- c) Vascular tissues
- d) Cone-bearing structures

Ans. b) Presence of flowers

2. In gymnosperms, the main site of photosynthesis is:
- a) Stem
 - b) Root
 - c) Leaf
 - d) Cone

Ans. c) Leaf

3. Which of the following structures is responsible for reproduction in gymnosperms?
- a) Fruits
 - b) Flowers
 - c) Cones
 - d) Spores

Ans. c) Cones

4. What type of root system is present in Pinus?
- a) Taproot
 - b) Fibrous root
 - c) Adventitious root
 - d) Rhizoidal root

Ans. a) Taproot

5. The reproductive structures in Pinus are called:
- a) Seeds
 - b) Flowers
 - c) Cones
 - d) Leaves

Ans. c) Cones

6. In Cycas, the reproductive organs are found in:
- a) Male and female cones on the same plant
 - b) Separate male and female plants
 - c) The same flower
 - d) The underground roots

Ans. b) Separate male and female plants

7. What is the main dispersal method for Pinus seeds?
- a) Water
 - b) Wind



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- c) Animals
- d) Explosive dehiscence

Ans. b) Wind

8. Ephedra is an important gymnosperm because:
- a) It produces commercial timber
 - b) It has medicinal properties
 - c) It has edible seeds
 - d) It is a flowering plant

Ans. b) It has medicinal properties

9. The dominant generation in gymnosperms is:
- a) Gametophyte
 - b) Sporophyte
 - c) Prothallus
 - d) Mycelium

Ans. b) Sporophyte

10. The primary function of male cones in gymnosperms is:
- a) Seed protection
 - b) Pollen production
 - c) Photosynthesis
 - d) Water absorption

Ans. b) Pollen production

Short Answer Questions:

1. What are the vegetative parts of a gymnosperm plant?
2. Describe the reproductive structures of gymnosperms.
3. What is the main function of cones in gymnosperms?
4. How do gymnosperms differ from angiosperms in reproduction?
5. What is the economic importance of Pinus?
6. How is the life cycle of Cycas different from Pinus?
7. What are the medicinal properties of Ephedra?
8. Define dioecious and monoecious with reference to gymnosperms.
9. What role does wind play in gymnosperm reproduction?
10. Describe the significance of gymnosperms in the ecosystem.



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Long Answer Questions:

1. Describe the morphological features of the vegetative and reproductive parts of gymnosperms.
2. Explain the anatomy and reproduction of Pinus in detail.
3. Discuss the life cycle of Pinus with a labeled diagram.
4. Describe the anatomy, reproduction, and economic importance of Cycas.
5. Compare and contrast the life cycles of Pinus and Cycas.
6. Explain the reproduction process of Ephedra and its significance.
7. Discuss the evolutionary importance of gymnosperms in plant history.
8. What are the various economic uses of gymnosperms in different industries?
9. Explain the role of gymnosperms in environmental conservation.
10. Discuss the adaptations of gymnosperms for survival in different habitats.

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MODULE -3
ANGIOSPERMS

3.0 Objectives

- Understand the origin and evolution of angiosperms.
- Learn about primitive angiosperms and their characteristics.
- Explore angiosperm taxonomy, classification, and identification.
- Gain knowledge of taxonomic literature and botanical nomenclature.
- Understand the principles and rules of plant naming under the ICNafp.

UNIT 3.1

Origin and evolution, some examples of primitive angiosperms

3.1.1 Origin and Evolution of Angiosperms

The origin of **angiosperms (flowering plants)** has long been a fascinating topic in plant evolution. Angiosperms are seed plants distinguished by the presence of **flowers** and **seeds enclosed within fruits**, features that have made them the most diverse and ecologically dominant group of plants on Earth today. Fossil evidence shows that angiosperms appeared relatively suddenly in the **Early Cretaceous period (about 130–140 million years ago)**, a rapid rise that Charles Darwin famously called the “**abominable mystery**.”

Most scientists agree that angiosperms evolved from some group of ancient **seed ferns or gymnosperm-like ancestors**, possibly related to extinct groups such as Bennettitales or Caytoniales, because these groups show flower-like reproductive structures. The evolutionary success of angiosperms is linked to several key innovations:

- The **enclosure of ovules** in carpels, leading to fruits that protect seeds and aid dispersal.
- The development of **flowers**, which attract pollinators and allow efficient cross-pollination.
- **Double fertilization**, producing both an embryo and endosperm, ensuring nourishment for the young seedling.
- A wide range of growth forms and adaptations, allowing them to colonize diverse habitats.



3.1.1.1 Primitive Angiosperms

Among living angiosperms, certain groups retain many ancestral or **primitive characteristics**, giving clues to early angiosperm evolution. These are mostly found in the order **Magnoliales** and related basal lineages, often called “**primitive angiosperms**” because they show simple flower structures, numerous free floral parts, and spiral arrangements.

Examples include:

- **Magnolia** (*Magnolia grandiflora*): Flowers are large, bisexual, with spirally arranged petals and stamens on an elongated receptacle. Carpels are free and arranged in a cone-like structure, resembling ancient floral organization.
- **Michelia** (*Michelia champaca*, known as champak): Shows primitive features like numerous spirally arranged stamens and carpels, fragrant flowers, and a cone-like arrangement of reproductive parts.
- **Degeneria** (found in Fiji): A rare tree with primitive flower structures, free carpels, and many spirally arranged parts, considered close to the early angiosperm condition.
- **Austrobaileya** and **Illicium** (star anise): Both have simple, radial flowers with numerous tepals and free carpels, considered representatives of early diverging angiosperm lineages.

Summary:

Angiosperms (flowering plants) are the most advanced and diverse group of plants. They are believed to have originated during the **early Cretaceous period (~130–140 million years ago)** from ancestral seed ferns or gymnosperm-like ancestors (possibly Bennettitales or Gnetales). Early angiosperms were small, woody plants with simple flowers and undifferentiated perianth. Fossil evidence like *Archaeofructus* and *Austrobaileya* shows the gradual transition from gymnosperm-like ancestors to true flowering plants.

Primitive angiosperms show several ancestral characters such as: spiral arrangement of floral parts, indefinite number of floral organs, separate and free parts (apocarpous gynoecium), actinomorphic symmetry, superior ovary, and presence of both stamens and carpels (bisexual flowers).



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Multiple Choice Question (MCQs):

1. Angiosperms are believed to have originated during the:
 - a) Devonian period
 - b) Triassic period
 - c) Cretaceous period
 - d) Jurassic period

Ans: c) Cretaceous period

2. Which of the following is considered a living basal angiosperm?
 - a) Pinus
 - b) Amborella
 - c) Cycas
 - d) Selaginella

Ans: b) Amborella

3. A characteristic feature of primitive angiosperm flowers is:
 - a) Unisexual flowers
 - b) Fused floral parts
 - c) Spiral arrangement of floral parts
 - d) Zygomorphic symmetry

Ans: c) Spiral arrangement of floral parts

4. Which of the following shows apocarpous gynoecium?
 - a) Magnolia
 - b) Hibiscus
 - c) Mustard
 - d) Sunflower

Ans: a) Magnolia

5. Which fossil plant is considered close to early angiosperms?
 - a) Archaeofructus
 - b) Rhynia
 - c) Lepidodendron

d) *Glossopteris*

Ans: a) *Archaeofructus*



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Short Answer Questions

1. When did angiosperms first appear in the fossil record?
2. Mention two important features of primitive angiosperms.
3. What is meant by apocarpous condition?
4. Name any two living primitive angiosperms.
5. Why is *Amborella* important in angiosperm evolution studies?
6. Which gymnosperm groups are considered ancestral to angiosperms?

Long Answer Questions

1. Discuss the origin and evolutionary history of angiosperms.
2. Describe the major morphological characters of primitive angiosperms.
3. Give an account of important examples of primitive angiosperms with their features.
4. Explain the evolutionary significance of flowers in the success of angiosperms.
5. Write an essay on fossil evidence supporting the origin of angiosperms.



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UNIT 3.2

Angiosperms Taxonomy

Angiosperms, or flowering plants, are the most speciose and successful group of land plants on Earth. They outnumber the other two domains by a margin, with about 300,000 species of them recognized to date, and they rule terrestrial ecosystems around the globe and have immense ecological, economic, and cultural value. This group has been particularly successful due to the innovations of flowers and fruits that foster efficient pollination and seed dispersal. This thorough survey of angiosperm taxonomy reviews their vegetative and reproductive morphology, the history of classification systems, the objectives of taxonomic work, and the basic elements that form the foundation of contemporary classification of angiosperms. As common sense as it may be, the study of flowering plant diversity and its evolutionary bases and processes is highly informative for all aspects of plant taxonomy from what it is to how to best conduct it.

3.2.1 Vegetative Morphology (root-stem-leaf)

Angiosperms have evolved a wide-range of shapes and sizes for their vegetative structures as roots, stems and leaves, adapted to a plethora of environmental conditions and ecological niches. Such structures are common among flowering plants, with not only essential biological functions, but also important taxonomical features in plant classification. Morphological features of vegetative organs often correlate with phylogenetic relations and may offer insights into the evolutionary history and adaptations of angiosperm lineages.

3.2.1.1 Root Systems

The root system, which usually arises from the radicle of the embryo, performs several key functions: anchorage (eg, stability), uptake of water and nutrients, temporary storage, and, in some cases, specialized forms for specific ecological niches. In angiosperms, root systems are generally found as two primitive types such as taproot system and fibrous root system. Taproot systems, typical of most eudicots, have one large primary root that extends straight down into the soil, and small lateral roots that branch off of it. This structure gives it great anchorage and access to deep water, giving it an advantage in seasonal limited environments. Fibrous root systems, which are characteristic of monocots, contain many roots of similar diameter that extend from the base of the stems and create a dense, shallow system. In particular, this architecture favors soil stabilization and the effective use of nutrients and water in the three upper soil horizons. However, angiosperm roots also exhibit extraordinary morphological diversity indicative of



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specialized adaptations beyond these basic types. And storage roots, like those in carrots (*Daucus carota*) and sweet potatoes (*Ipomoea batatas*) are altered to act as accumulation reservoir of carbs and more nutrients. Some mangroves such as *Avicennia* and *Sonneratia* possess special root type in a er sub-string mud that is anaerobic, so they must extend their roots above ground to get gas exchange and air canalization called pneumatic. Additional mechanical support is given by prop roots, as in the case of corn (*Zea mays*) and certain tropical trees, such as *Pandanus*. Epiphytes such as many orchids and bromeliads have aerial roots that absorb both moisture and nutrients from the air. In parasitic plants such as mistletoes (*Viscum*) and dodder (*Cuscuta*), Haustorial roots can penetrate into host tissues in order to access water and nutrients. In many geophytes, as contractile roots develop, they tug the plant deeper into the soil. Trees collected from tropical rainforests often have pronounced buttress roots that provide mechanical plant stability in shallow soils. Provided that aim with symbiotic relationships is widely used by about 90% of angiosperm species so, mycorrhizal associations in relation to a fungal indicates, increase nutrient absorption capacity.

It has also been shown that root anatomical traits are taxonomically informative (except for the Alismatales), although this has not been the focus and may not be well known in its own right. For particular taxonomic groups, the organization of the vascular cylinder (stele), the number of xylem poles (diarch, triarch, tetrarch, polyarch), the presence of specialized storage compounds (e.g. inulin in Asteraceae), and cell types (passage cells in endodermis e.g. *Nardus stricta*) can be diagnostic. Root hairs, extensions of epidermal cells that greatly enhance the absorptive surface area, differ in abundance, length, and persistence in angiosperm lineages. These characters, often subtle and below-ground dominated, when they do occur in the fossil record can be extremely informative to taxonomic and environmental classifications, and reflect key adaptation to the wide ecological ranges throughout our planet.

3.2.1.2 Stem Morphology

For angiosperms, stems are the plant body's physical support structure, as well as conduits for water and nutrient, food storage and often, photosynthesis. Such variation is achieved through differences in the morphology of stems, the structure of which varies greatly in flowering plants (angiosperms), driven by adaptations to different habitats, life histories, and ecological strategies. Stems can grow in different habits that determine the shape of the plant as a whole: trees have a woody, perennial stem that supports a thick crown of foliage while shrubs have many persistent woody stems that develop near ground level; herbs have soft non woody stems; climbers who uses different mechanisms



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to grow upward towards the light source; and creeping or prostrate forms that grow horizontally along the ground or surface. Leaves are arranged on stems according to a regular pattern called phyllotaxy, and in many cases the profiles of phyllotaxy patterns are specific for certain taxonomic groups. Common arrangements of phyllotaxis include what is called alternate (where you have one leaf attached to a node which is placed against the others, thus forming a spiral arrangement), opposite (two leaves arranged in relation to one another at 180° per node) and whorled (three or more per node). Divergence angles — between successive leaves — often approximate mathematical constants like the golden angle (about 137.5°), optimizing for light interception and spatial arrangement. Leaves attach to the stem at nodes, which may be solid or hollow, and in some plants additional structures at the node (such as stipules or leaf sheaths) are useful taxonomic characters. There are many modifications of stems that will have specific functions that tend to be characteristic of certain taxonomic groups. Rhizomes are horizontal underground stems that serve as organs for vegetative propagation and perennation, such as ginger (*Zingiber officinale*) and many ferns. Horizontal stems running above ground that produces new plants at nodes (stolons or runners), as in strawberry (*Fragaria*) Corms (not to be confused with bulbs) are vertical underground storage stems surrounded by dry scale leaves, a trait of *Crocus* and *gladiolus*. Tubers are swollen, storage-focused portions of rhizomes or stolons, with potato (*Solanum tuberosum*) recognized as a common example. Bulbs, typified by onions (*Allium*) and lilies, are short beige vertical stems clad with fleshy storage leaves. In such a case, flattened photosynthetic stems mimic and function as leaves, as in *Ruscus* and many cacti. Tendrils that help climb; they may be modified stems, as seen in grape (*Vitis*). Thorns are pointed defensive alterations of stems, such as in *Crataegus*.

Stem anatomy offers further taxonomically informative characteristics. Monocots and eudicots also have a different organization of vascular tissues! In eudicots, the vascular bundles are arranged in a ring of cambium that allows the plant to undergo secondary growth to produce secondary xylem (wood) and secondary phloem. This anatomy enables the evolution of woody stems repeatedly within numerous eudicot lineages. By contrast, monocot stems lack true secondary growth, with no vascular cambium, scattered vascular bundles throughout the ground tissue, and most groups achieve an increase in diameter through primary thickening, as with palms. Presence and distribution of specialized cells and tissues—such as the laticifers (latex-containing cells), secretory canals, sclereids, and fibers—often define certain families or genera. Characters such as vessel element size and arrangement, ray structure, fiber types, and the presence or absence of axial parenchyma, growth rings, and reaction

wood contribute to the diversity of taxonomically informative characters found in wood anatomy of woody taxa.

3.2.1.3 Leaf Morphology

Leaves are the major photosynthetic organs of angiosperms, and they exhibit tremendous diversity of form, structure and arrangement. This diversity offers a treasure-trove of taxonomically valuable traits and is representative of adaptations to divergent environmental conditions and ecological strategies. Leaf morphology is particularly useful for taxonomic identification as leaves are easily observed, often available for much of the growing season, and frequently possess features that are distinctive of certain taxonomic groups. The arrangements or distance between leaves on a stem (that is, leaf arrangement or phyllotaxy) can be classified, primarily, into alternate (with one leaf per node, and typical of many families, including the Fagaceae and Rosaceae) opposite (two leaves per node, which is found in, among others, the Lamiaceae and Rubiaceae families) and whorled (three or more leaves per node, as with the Apocynaceae. Other plants have basal or rosette leaf arrangements, such as Plantago, with their leaves clustered together at the base of the stem. Another basic taxonomic character involves leaf composition: simple leaves have an unbroken blade (maple, oak), while compound leaves have a blade divided into multiple, positive leaflets. Compound leaves may be pinnately compound, with leaflets arranged along a central rachis (rose, ash), palmately compound with leaflets radiating from a central point (horse chestnut) or further divided into bipinnate or tripinnate forms (many legumes). The presence and morphology of stipules (paired appendages at the base of the leaf) and their persistence provide further taxonomic information.

Leaf shape shows remarkable variation (even in human terminology), described by terms including linear (long and narrow, as in many grasses), lanceolate (lance-shaped, broader at base and tapering to apex), ovate (egg-shaped, broader at base), elliptic (broadest at middle), obovate (egg-shaped, broader at apex), cordate (heart-shaped), reniform (kidney-shaped), sagittate (arrowhead-shaped), and peltate (with petiole attached to lower surface rather than margin). Leaf apices can be acute, acuminate, obtuse, truncate, or emarginate; leaf bases are similarly diverse with cuneate, rounded, cordate, and asymmetric forms. Leaf margins can be entire (smooth), serrate (with little teeth pointing toward acme), dentate (little teeth pointing outward), crenate (rounded teeth), lobed (indentations extending less than halfway to midrib), or undulate (wavy). Mounting evidence suggests that leaf venation contributes to significant taxonomic distinctions. Most of the monocots are characterized by the presence of parallel venation: the veins are arranged in a parallel manner from the base to the apex of the



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leaf. It is otherwise known as pinnate venation where one midrib runs down the leaf and several secondary veins branch from it and is typical in many eudicots. Palmate venation, with multiple primary veins arising at a single point at the base of the leaf, takes place in plants such as maple and sycamore. A characteristic of most eudicots is reticulate (net like) venation in which the veins form an interconnected network. Structurally and morphologically distinct from the politis (overlapping venation), the shape of areoles (smallest units created by veins) has always been of taxonomic interest, especially in distinguishing higher orders of venation, as well as from the perspective of morphological and phylogenetic properties.

Leaves exhibit many specialized adaptations that reflect adaptations to specific ecological niches. In plants of arid environments, succulent leaves with water-storing tissues are present (Aloe, Crassula). Tendrils, such as in pea (*Pisum*), aid in climbing. Examples of defensive adaptations of plants are the spines, such as in the case of barberry and cacti. Leaves of certain plants, such as sundew (*Drosera*) and pitcher plants (*Nepenthes*, *Sarracenia*), have evolved trapping structures to catch the unsuspecting insects! This adaptation, in the form of scale leaves, less protective structures, is common in many bulbs and on some stems. Aquatic plants, such as water lilies (*Nymphaea*), have floating leaves that are adapted for buoyancy and gas exchange. Some constituent features of the leaf surface enhance additional taxonomic contributions. Trichomes (hair-like structures) are highly diverse in terms of their density, structure (simple, branched, stellate, peltate) and functions (protective, secretory, absorptive). Some taxa show characteristic patterns of bloom or glaucousness on leaf surfaces due to the presence of epicuticular waxes. Stomatal distribution (amphistomatic with stomata on both surfaces, hypostomatic with only lower surface having stomata, or epistomatic with only upper surface having stomata) and stomatal complex type (anomocytic, anisocytic, paracytic, diacytic, or tetracytic) often reflect taxonomic groupings. Certain taxa may be characterized by the presence of structures such as extrafloral nectaries, hydathodes (water-secreting structures) and various gland types. Leaf anatomy adds additional taxonomic characters. Mesophyll tissue can either be dorsiventral (meaning distinctly palisade and spongy layers and characteristic of most of the eudicots) or isobilateral (meaning similar arrangement of tissue on both sides, typical of the monocots and some eudicots that have vertically-oriented leaves). Other types of secretory cells or tissues—like the cells containing calcium oxalate crystals, latex ducts, oil cells, or idioblasts—are generally specific to certain taxons. Special features associated with habitats such as xeromorphy (thick cuticle, sunken stomata, hypodermis for dry habitats) or hydromorphy (aerenchyma, reduced vascular tissue, and reduced mechanical support for aquatic

environments) could be applied for ecological and taxonomical questions.

3.2.2 Reproductive Morphology

Angiosperm reproductive structures are some of the most diagnostic and taxonomically informative features in botanical systematics. The flower is a distinctive innovation of angiosperms and their fruits and seeds also show high diversity according to their modes of pollination and dispersal. These reproductive features have been the heart of angiosperm classification since Linnaeus, and remain some of the most important characters for modern taxonomic systems.

3.2.2.1 The Flower: The flower is the signature reproductive structure of angiosperms, showing extreme diversity among taxa combined with a basic structural blueprint. Such diversity is representative of adaptation to various pollination mechanisms, reproductive strategies and ecological niches. Floral morphology is critical for angiosperm taxonomy, as floral characters are often better indicators of phylogenetic relationships than other morphological characters. Morphological and anatomical details about flower organization serve as taxonomically informative characters. These include actinomorphic (radially symmetrical, as with the flower of *Rosa*), zygomorphic (bilaterally symmetrical, as with the flowers of the *Orchidaceae* and *Fabaceae*), and asymmetrical (irregular, as with the flowers of *Canna*) forms. Floral merosity is the number of parts in each floral whorl, with trimerous (parts in threes) flowers being typical of monocots, and tetramerous (parts in fours) or pentamerous (parts in fives) patterns prevailing in eudicots. The perianth, which may be differentiated into calyx (sepals) and corolla (petals), differs from distinctive calyx and corolla (heterochlamydeous, as in *Roseae*) to undifferentiated with tepals rather than distinct sepals and petals (homochlamydeous, as *Liliaceae*) to absent/very reduced (achlamydeous, as in many wind-pollinated taxa). The receptacle (the upper enlarged end of the floral stalk where the floral organs are inserted) may be flat, convex, concave, or developed into various forms such as the hypanthium seen in many members of the *Rosaceae*. There are many taxonomically informative characters from the floral parts. Sepals, green protective structures that are the outermost floral whorl (calyx), can be separate (polysepalous) or fused (gamosepalous) and may persist into fruiting in some taxa or be lost early in others. Petals, typically colored structures making up the second floral whorl (corolla), play a main role in attracting pollinators. They may be distinct (polypetalous) or united (gamopetalous), regular or irregular, and often modified into specialized structures to attract pollinators, such as spurs, keels or landing platforms. The variety of petal and sepal morphology illustrate



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adaptations to different pollination syndromes and constitute important diagnostic characters for numerous plant families.

The androecium, or male reproductive whorl of stamens, shows a remarkable diversity of forms and arrangements. A stamen typically comprises a filament, which holds up an anther that produces pollen. Diagnostic floral characters include the number of stamens (from 1 to many), their disposition (free, fascicled in bundles, monadelphous with all filaments united in a single tube, diadelphous in two groups, or polyadelphous in several), the type of anther dehiscence (longitudinal slits, pores, or valves), modified connectives, and the presence of staminodes (sterile stamens). Some families have very distinctive stamen fusion patterns: Malvaceae have monadelphous stamens, many Fabaceae have diadelphous stamens, and Asteraceae have syngenesious stamens (anthers fused but filaments free). Some of the most taxonomically useful source of information is that from the gynoecium, the whorl of the flower responsible for the formation of ovules and seed, consisting of one to more than several fused carpels. There is an ovary with ovules, a style, and a stigma receiving pollen in each carpel. Carpel number (one–many), fusion pattern (apocarpous with disjunct carpels as in Ranunculaceae; syncarpous with fused carpels as in Solanaceae), ovary position (superior with the ovary located above other floral parts or inferior with ovary below the attachment of other floral parts), placentation type (axile, parietal, free-central, basal, or laminar, describing ovule arrangement within the ovary), style number and position and stigma morphology are all taxonomically informative characters. These gynoecial features combined are often used to define major taxonomic groups; for example many Malvaceae have a pentacarpellate syncarpous gynoecium with axile placentation and superior ovary.

Other taxonomic insights are provided by floral adaptations related to pollination. Pollination syndromes are sets of floral traits that are adapted to particular pollinators: bird-pollinated flowers tend to have tubular red corollas and large amounts of nectar; moth-pollinated flowers tend to be white and fragrant at night; bee-pollinated flowers tend to have landing pads and visual nectar guides. (sneaters (nectar-producing structures), osmophores (scent-emitting organs), coronas (extra whorls of tissue between petals and stamens, e.g., in Passiflora), spurs (hollow projections that form at some petals or sepals and have nectar inside), and countless adaptations that define the evolution of discrete taxonomic units. These systems, which relate to adaptations associated with either outcrossing or selfing, include adaptations such as dichogamy (temporal separation of male and female functions), herkogamy (spatial separation of anthers and stigma), self-incompatibility systems, and the evolution of unisexual flowers (monoecious with separate flowers for male and female on the same



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plant, or dioecious with male and female flowers on separate plants). That is, the manner in which the flowers are arranged on the floral axis—referred to as inflorescence—affords key taxonomic information. The main types of inflorescence are racemose or indeterminate types, in which the main axis continues to grow with the oldest flowers at the bottom, and cymose or determinate types, where the main axis terminates in a flower. The raceme (pedicelled flowers on an elongate axis, as in foxglove), spike (sessile flowers on an elongate axis, as in *Plantago*), spadix (fleshy axis on a spike, *Araceae*), catkin or ament (pendulous spike of unisexual flowers, as in willows), corymb (flat-topped raceme with longer pedicels toward the outer circle, *Iberis*), umbel (pedicels of flowers arising from a single point, defining *Apiaceae*), capitulum or head (group of sessile flowers tightly clustered on a receptacle, defining *Asteraceae*) are examples of racemose inflorescences. Monochasial cymes are cymose inflorescences in which all axes produce one branch (as in *Hemerocallis*), dichasials are those in which all axes produce two branches (prevalent in *Caryophyllaceae*), and pleiochasial are those in which all axes produce many branches. Special types of inflorescence include cyathium (cup-like structure containing reduced flowers; characteristic of *Euphorbiaceae*), hypanthodium (fleshy receptacle with flowers on the inner surface; *Ficus*), and verticillaster (a condensed cyme that has the appearance of a whorl; *Lamiaceae*). Inflorescences are often characterized by their pattern and structure. These characteristics are useful in taxonomically identifying inflorescences at a family and genus level.

3.2.2.2 Fruits and Seeds: The mature ovaries enclosing seeds (known as fruits) and seeds themselves are essential source of taxonomic information. Different types of fruits correlate with different dispersal mechanisms and ecological adaptations, while seed structure is sometimes associated with evolutionary lineages and germination strategies. Summary Sporophyte reproductive structures have been integral to angiosperm classification from its earliest beginnings, and they remain the primary source of diagnostic characters in contemporary taxonomic systems. Fruiting structures Fruits are classified taxonomically on the basis of the characters that are descriptive of their taxa. This basic differentiation can be further classified based on their development pattern, as simple (develops from a single flower with one or fused carpels, e.g. cherry), aggregate (develops from a single flower with separate carpels, e.g. raspberry), or multiple/collective (develops from an inflorescence, e.g. pineapple or fig). Based on the number of carpels, fruits can be: (a) monocarpous (derived from a single carpel, e.g. legumes); (b) apocarpous (derived from multiple separate carpels, e.g. strawberry or magnolia); (c) syncarpous (derived from multiple fused carpels, e.g. tomato or apple) Similar to the flower, where ovary position is correlated with fruit



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structure, superior (epigynous), inferior (hypogynous), or half-inferior fruits (perigynous) correspond to the position of the original ovary. Dry fruits are distinguished from fleshy fruits by the nature of the pericarp (fruit wall) and dehiscent fruits (which open to disperse seeds) from indehiscent fruits (which do not).

Many families and genera of plant host have diagnostic and distinguishing features of the major fruit types. Dehiscent dry fruit types — follicle one carpel, opens at one suture; e.g. in Asclepiadaceae; legume one carpel, opens at two sutures (Fabaceae); siliqua (2 fused carpels with replum, Brassicaceae), silicle (siliquae < 1 cm); capsule multiple fused carpels, opens variously, e.g. *Lilium*, *Papaver* & many other taxa. Examples of dry indehiscent fruits include achene (one-seeded fruit with free pericarp, Asteraceae), caryopsis (one-seeded fruit with fused pericarp, Poaceae), cypsela (inferior achene, Asteraceae), nut (one-seeded fruit with hardened pericarp, such as *Quercus*), samara (winged achene, *Acer*, *Fraxinus*) and schizocarp (splitting into mericarps, Apiaceae, Malvaceae). Fleshy fruits: berry (entirely fleshy, multi-seeded, *Solanum*); drupe (fleshy with stony endocarp surrounding a seed, *Prunus*); pome (fleshy with papery endocarp, *Malus*); hesperidium (modified berry with leathery rind, *Citrus*); pepo (modified berry with hard rind, Cucurbitaceae)

Seed endocarp structure contains supplementary taxonomic information reflecting both evolutionary relationships and ecological adaptations. The three basic parts of a seed include the embryo, the food storage tissue, and the seed coat. Important seed characteristics for taxonomy are form (linear, bent, folded, peripheral, curved), position (axile, basal, peripheral, ruminant), cotyledons (number and structure, monocotyledonous or dicotyledonous; shapes include lanceolate, ovate, serrated, spatulate, etc., with smooth, rough or hairy texture), food storage tissue (endospermic with or without endosperm, nonendospermic with food in cotyledons or perispermous with perisperm), and seed coat (texture, ornamentation; appendages such as arils, wings or hairs; hilum position and size; micropyle orientation). This is why specialized adaptations regarding these dispersal mechanisms have evolved, such as: elaiosomes (fleshy appendages there to attract ants), hooks, barbs, mucilaginous seed coats, flotation devices, etc. In fruit and seed morphology not only useful taxonomical material are discovered but also they are closely related to environmental adaptation, especially to the dispersal mechanisms. Many families of plants can be readily recognized by their distinctive fruits: legumes form pods; mustards form siliques; composites form achenes with pappus; grasses form caryopses; and roses form aggregates of achenes or drupelets. Likewise, particular groups are often characterized by their seeds: orchids by their dust-like seeds,



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parasitic plants by their diminutive embryos, and many aquatic plants by their specialized flotation tissues.

Flowering plants have changed greatly over time since the establishment of their systematic classification, shaped by novel methods, data, and ideas. Such a historical view shows how angiosperm taxonomy has evolved in sensitivity to issues of both practical categorical utility and striking evolutionary relationships, how systems change from era to era, but build incrementally upon some aspects of or revolutionize previous comprehension. Ancient systems for classifying plants focused, for the most part, on practical applications or general growth forms rather than on natural relationships. Theophrastus (371-287 BCE), sometimes referred to as the "father of botany" (Linnaeus later named an order of plants after him) and who wrote "Historia Plantarum" and "De Causis Plantarum," divided plants into trees, shrubs, and herbs as well as describing differences in organ morphology relative to reproduction. Archaic Sino-Indian and Oryental herb note traditions, likewise, progressed to a framework of associations related largely to pharmacological effects and growth-forms. While these early approaches were not evolutionary in the modern sense, they laid important observational groundwork and helped establish the importance of comparative plant morphology. The Renaissance period made great strides in the classification of plants as global exploration expanded knowledge of botany and the invention of printing brought information dissemination into the picture. Andrea Cesalpino proposed a system in his "De Plantis" (1583) utilizing fruit and seed characteristics, one of the first to utilize reproductive structures for classification. The English naturalist John Ray reviewed much of the previously known material in his *Historia Plantarum*, identifying two major groups, the monocotyledons and dicotyledons, and stressing that classification must be based on several characters rather than a single one. His was a hybrid system, one that included both vegetative and reproductive features, and it laid the groundwork for more natural systems to come.

A fundamental event in the history of plant taxonomy was the introduction of a binomial system by Carl Linnaeus in the "Species Plantarum" (1753), establishing a stable framework for naming plants with the exclusive use of genus and species names. Linnaeus's sex system classified plants based mainly upon the number and arrangement of stamens and pistils. Such an artificial system had the advantage of being practical for identification purposes, although at its core it was revolutionary, and it placed plants together that may not have been at all closely allied. For instance, it grouped plants with five stamens and one pistil together irrespective of other features, lumping unrelated groups like primroses and nightshades. However, Linnaeus's binomial nomenclature and focus on reproductive characters offered



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critical underpinnings for the taxonomic work that followed. Natural classification systems, which sought to reflect true evolutionary relationships, began to evolve in the late 18th and early 19th centuries, predating Darwin's theory of evolution. In the latter half of the 18th century, Antoine-Laurent de Jussieu published a work detailing a system of classification for genera (rather than species), called the "Genera Plantarum", published in 1789; Jussieu recognized plants as possessing specific traits and characterized them into families based on many characters, but especially overall morphological similarities. In his "Théorie élémentaire de la botanique", Augustin Pyramus de Candolle expanded upon natural classification and initiated the monumental "Prodromus Systematis Naturalis Regni Vegetabilis", an account of all known plants arranged in a natural system.

The world of taxonomy was revolutionized by the publication of Darwin's "Origin of Species" in 1859, which created the theoretical foundation necessary to derive phylogenetic classification from evolutionary history. This paradigm shift slowly transformed botanical classification, as taxonomists started to interpret morphological similarities as evidence of common ancestry rather than as arbitrary similarity. The "Genera Plantarum" (1862-1883) of George Bentham and Joseph Dalton Hooker took this debate nearer, because it was yet evolutionary, yet usable. Eichler, A.W., *Blüthendiagramme* and one of the earliest explicit phylogenetic systems for flowering plants, based on floral structure and development. There were competing approaches to plant classification in the late 19th and early 20th centuries. The German botanist Adolf Engler, in company with Karl Prantl, created a widely used system he published, in a work called "Die natürlichen Pflanzenfamilien", which organized flowering plants into monocotyledons and dicotyledons, starting with believed primitive forms — those with simple flowers and absent petals — and moving into more complex types. For most of the 20th century this system ruled classification of angiosperms. A completely different system, one developed by Charles Edwin Bessey and introduced in his 1915 book "The Phylogenetic Taxonomy of Flowering Plants," classified these as primitive forms rather than advanced forms, focusing on the idea of petaloid flowers that had parts that fit together. These contrasting systems represented different interpretations of evolutionary direction in blossom evolution. Various taxonomic schools were developed that represented significant advances in the 20th century. Numerical taxonomy, or phenetics, as it was popularized by Robert R. Sokal and Peter H. A. Sneath in the 1960s, did use quantitative methods, but was less concerned with evolutionary relationships, instead grouping organisms based on overall similarity. (Phylogenetic systematics (cladistics) emphasized shared derived characters (synapomorphies) as indicators of evolutionary relationships (Will Hennig). Evolutionary



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taxonomy, promoted by Ernst Mayr and G. G. Simpson, tried to factor in both ancestry and degree of divergence. Arthur Cronquist developed an influential angiosperm classification system used in "An Integrated System of Classification of Flowering Plants" which was an evolutionary taxonomic system, maintaining traditional dicots and monocots but arranging families in an assumed evolutionary sequence.

Molecular data has transformed modern angiosperm taxonomy. DNA sequencing methods, which took off in a big way in the 1980s, were giving scientists unprecedented glimpses at plant relationships. Gift of the Angiosperm Phylogeny Group in which the authors of each group of angiosperms represent a group of molecular phylogenetic evidence into the insectivorous and some non-insectivorous plants. This system has dramatically reshaped traditional groupings, and major clades are now recognized, such as basal angiosperms, magnoliids, monocots, and eudicots, with the former traditional dicots now recognized as being paraphyletic. APG system stresses monophyly and resulted in the membership of many families being changed and others dissolved. Molecular data are becoming an increasingly intrinsic part of contemporary angiosperm taxonomy that harmonizes morphological, anatomical, developmental, and ecological data into an overall taxonomy. The availability of next-generation sequencing technologies, capable of generating whole-genome-scale data rapidly, has further improved our understanding of the relationships among angiosperms. Modern taxonomic best practices increasingly include concern for conservation, particularly given that accurate and complete classification is essential to protecting biodiversity. Digital technologies enable collaborative work across the globe, global data synthesis, and the transformation of taxonomic information into interactive identification tools that are readily usable by nonprofessional collectors. With data extending back centuries of botanical knowledge, but a new level of understanding using the most advanced methodologies available today, this integrative approach is the current frontier of angiosperm taxonomy, shedding new light on the evolutionary history and relationships of flowering plants.

The basic goals of angiosperm taxonomy are both interlinked and of differing scientific and practical nature. While these goals have developed through time in light of shifting scientific paradigms, technological abilities and societal requirements, they continue to be focused on documenting, organizing and comprehending the incredible diversity of flowering plants.

Identification and recognition of plant species is a key objective of taxonomy, constructing systems that facilitate the accurate determination of plant identity. This goal addresses fundamental science and offers practical potential for agriculture, forestry,



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conservation, and horticultural applications. In order to help with identification, taxonomists produce diagnostic keys, written descriptions, and images that emphasize differentiating traits. Examples of modern methods include digital ID tools, interactive keys, imaging systems, and DNA barcoding methods that identify species from small pieces of plant or animal tissue. Examples of identification needs are practical, from the identification of medicinal plants and agricultural weeds to the monitoring of endangered species and the identification of invasive taxa. These Classification and systematics of angiosperms provide support and efficient management of biological information into a cohesive hierarchical framework. This organization allows scientists to communicate with one another and gives a structure to compare and contrast different plant groups. Classification systems categorize taxa into hierarchies (species, genera, families, orders, etc.) that reflect relationships and similarities, which permits scientists to make predictions and generalizations about certain characteristics of plants. Such organizing activity is also a part of used in practical purposes like designing botanical gardens, herbaria collections, collective agricultural and horticultural databases, etc. Good classification systems find a balance between stability (to enable ongoing communication) and flexibility (to accommodate new findings).

As a result, reflecting evolutionary relationships between flowering plants in taxonomic systems has become a primary goal of modern taxonomy. In this case, a phylogenetic approach attempts to define organisms through their evolutionary history, thereby clustering organisms that share a common ancestor. This branch of taxonomy has been transformed by modern molecular techniques, providing relationships that were previously masked by convergent evolution or morphological reduction. The approach of the APG system exemplifies this goal, reordering traditional groupings according to monophyletic lineages supported by molecular data. This evolutionary framework is fundamental for character evolution, biogeographic patterns, and diversification rates within angiosperm lineages. By representing evolutionary relationships, taxonomic systems are predictively and explicatively, rather than merely descriptively, powerful. A stable and universal system of naming plants is essential for clear scientific communication. Plant taxa are governed by the International Code of Nomenclature for algae, fungi, and plants (ICN), which establishes a unique name for every plant that is accepted globally. This goal of nomenclature seeks to address the fundamental requirement of clear communication for plant diversity across languages, cultures, and temporalities. Consistency in naming allows for the literature to be searchable, databases to be built, and information to be pulled from the databases, while the principle of priority (the first name validly



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published gets the first chance in line to take precedence) maintains historical continuity. Such nomenclatural functions are enhanced by modern efforts such as the International Plant Names Index and by collaborative nomenclatural databases tracking names and their use, to avoid confusion caused by synonyms and homonyms. Documentation and description of biodiversity is an essential first step in conservation action and ecosystem management. Taxonomists are responsible for finding, describing and sorting plant species by noting their morphological characteristics, their geographic spread, role in the ecosystem, conservation status. The need for this aim of documentation has become even more pressing as biodiversity is increasingly threatened by habitat destruction, climate change, invasive species, and overexploitation. Comprehensive inventories of regional floras serve as baseline data sets for monitoring shifts in plant communities, whereas detailed descriptions of taxa allow for the identification of rare or threatened species. Modern practices combine traditional taxonomic documentation with methods through which digitisation can greatly reduce the effort, such as online databases, geographic information systems and citizen science initiatives that allow for documentation efforts to be scaled up.

Another useful goal is to predict properties and relationships of understudied species from their position in a taxonomic tree. Taxonomic classifications can be very useful for predicting things about chemical compounds, ecological interactions or potential uses of plants by examining how closely related they are to better-known relatives. The predictive power noted has applications in ethnobotany, pharmacognosy, etc. For instance, knowledge that a newly discovered plant belongs to a clade rich in alkaloids could prompt its prioritization for pharmaceutical screening, and knowledge that a species belongs to a nitrogen-fixing clade might indicate that it is a candidate for soil improvement. As classification systems increasingly reflect evolutionary relationships, the predictive potential of classification systems becomes more efficient, and the practical utility of phylogenetic approaches rises. Such integration with other biological disciplines enhances the explanatory power and utility of taxonomic systems. Contemporary taxonomy seeks to integrate and reconcile data from morphology, anatomy, palynology, embryology, cytology, phytochemistry, molecular biology, ecology, and biogeography. Integrative methods yield classifications that are both informed by and informative for diverse biological disciplines. Developmental studies can identify homologies across taxa, ecological studies can elucidate the adaptive significance of morphological traits, and biogeographic studies can relate distribution patterns to evolutionary history. As biology continues to become more interdisciplinary, taxonomy stands



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as an integrative framework bringing together widely diverse aspects of plant science.

Summary:

Angiosperm taxonomy is the science of **identifying, naming, describing, classifying, and arranging flowering plants** based on their similarities and differences. It helps in understanding plant diversity, evolution, and relationships. The study involves **nomenclature (naming rules), classification (grouping), and identification (recognizing species).**

Taxonomy has evolved through several stages:

- **Artificial systems** (e.g., Linnaeus): Based on a few characters like number of stamens and carpels.
- **Natural systems** (e.g., Bentham and Hooker): Based on overall morphological similarities.
- **Phylogenetic systems** (e.g., Engler and Prantl, Hutchinson, Takhtajan, APG system): Based on evolutionary relationships, molecular data, and genetics.

Multiple Choice Question (MCQs)

1. The branch of biology dealing with classification of plants is:
 - a) Ecology
 - b) Taxonomy
 - c) Genetics
 - d) Anatomy
2. Bentham and Hooker's system of classification is:
 - a) Artificial
 - b) Natural
 - c) Phylogenetic
 - d) Numerical

Ans: b) Taxonomy

Ans: b) Natural



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3. Which of the following is a phylogenetic system of classification?
- a) Linnaeus
 - b) Bentham and Hooker
 - c) Engler and Prantl
 - d) Theophrastus

Ans: c) Engler and Prantl

4. Angiosperms are divided into:
- a) Monocots and dicots
 - b) Bryophytes and pteridophytes
 - c) Gymnosperms and algae
 - d) Fungi and lichens

Ans: a) Monocots and dicots

5. The APG system of classification is based mainly on:
- a) Floral morphology
 - b) Molecular and genetic data
 - c) Vegetative anatomy
 - d) Palynology

Ans: b) Molecular and genetic data

Short Answer Questions

- 1. Define taxonomy.
- 2. Name the three main aims of plant taxonomy.
- 3. What are artificial and natural systems of classification?
- 4. Give two differences between monocots and dicots.
- 5. What is biosystematics?
- 6. Mention one example of a modern phylogenetic classification system.

Long Answer Questions

- 1. Describe the historical development of angiosperm classification systems.



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2. Discuss the major features and merits of Bentham and Hooker's system.
3. Write a note on the APG system of angiosperm classification.
4. Explain the role of modern tools (cytology, molecular data) in plant taxonomy.
5. Describe the hierarchy of taxonomic categories with suitable examples.
6. Write an essay on the importance and applications of angiosperm taxonomy.

UNIT 3.3

Identification, keys taxonomic literature

3.3.1 Taxonomic Hierarchy

Living organisms are classified in a hierarchical manner; the system was started by Carl Linnaeus in the 18th century and has been modified a lot since then. The taxonomy is based on the classification of the common progenitor from the scope of life on the planet. This is basically a hierarchy of the organisms in question, the more they move up the globalization ladder the more specific each, conquering level is. Taxonomic ranks range from most general (domain) to most specific (species): domain, kingdom, phylum (division for plants), class, order, family, genus, and species. And this hierarchy is reflective of evolutionary history, because organisms that belong to the same grouping have more recent universal common ancestors to each other than to those in other groups. For instance, all species within a genus have a more recent common ancestor with one another than with species in other genera, and all genera within a family have a more recent common ancestor with one another than with genera in other families. A taxonomic category, the domain is the highest rank and there are three recognized domains: Bacteria, Archaea, and Eukarya. Kingdom is the next higher level of classification including major groups like Animalia, Plantae, Fungi and different microbial kingdoms. The level of phylum (division in plants) groups organisms based on similar body plan. For example, Chordata encompasses all animals that have a notochord, and Arthropoda includes joint-legged invertebrates.

Classes are major subphyla, including Mammalia, Aves, and Reptilia under Phylum Chordata, and the classes Insecta and Arachnida under Phylum Arthropoda. Orders divide the classes into groups with even more specific shared characteristics. Families (a group of closely related genera) are often recognizable by shared features visible to the naked eye. Species forming the genotaxa can be further fused to visualize closely-related species that share a recent ancestral history at the genus level, while the species level represents populations with the capability of interbreeding in a natural setting and producing fertile offspring. A key idea of binomial nomenclature, created by Linnaeus, is that each organism is given a scientific name that consists of its genus and species, like humans being called *Homo sapiens* or white oak trees being called *Quercus alba*. This international guide gives biologists everywhere a standard reference, one that applies, no matter what the spoken language is, and no matter the range of names or variations, some of which can confuse even trained scientists, but which everyone remembers best. Taxonomy as we know it has actually



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grown from this lineage and now recognizes several levels of classification between that of genus and species, including subphylum, superclass, subclass, infraclass, superorder, suborder, superfamily, subfamily, tribe, subtribe, subgenus, and subspecies. These higher ranks facilitate the articulation of complicated evolutionary bonds. For example, primates (lemurs and lorises) are divided into the suborders Strepsirrhini and Haplorrhini (tarsiers, monkeys, and apes), based on their divergence along independent evolutionary paths. Taxonomy is not arbitrary as it tells us about the evolutionary relationships between various groups based on the analysis of morphological, anatomical, biochemical, behavioral, and genetic evidence. This is where the hope is, to find a taxonomy which ultimately describes the tree of life, that is, a classification system which organizes biological diversity according to evolutionary descent. This hierarchical system serves as both a basis for organizing biodiversity information and a communication apparatus, allowing predictions about the properties of unstudied organisms based on a given taxonomic placement, and revealing evolutionary patterns and processes. They are treated as a living system, is dynamic and constantly honed as new data and analytical methods become available. The development of molecular techniques, most notably DNA sequencing, has caused substantial overhaul of traditional classifications. Molecular data has shown that birds are a subset of dinosaurs and therefore unrecover the class of Aves from the clade of Reptilia. For example, whales and hippopotamuses have been reclassified within the Artiodactyla order due to the molecular evidence that they are related.

3.3.1.2 Morphological Identification

Morphological identification is the historical basis of taxonomy and continues to be fundamental for the study of biodiversity, field ecology, and many applied aspects of biological classification. For identification, this approach uses visible physical traits—from overall anatomical form to minute histological structures. The exact features employed differ considerably between taxonomic groups but typically consist of exterior traits such as size, shape, colour patterns and specialized structures, along with internal morphology, tissue organization and developmental history. In plant taxonomy, identification is often achieved demographically through reproductive structures (flowers and fruits), typically less environmentally plastic than vegetative characters. Features such as flower symmetry, floral parts number and arrangement, inflorescence type, fruit structure, and seed characteristics are important. In addition vegetative characters are often diagnostic as structures such as leaf arrangement, venation patterns, and presence of specialized structures—stipules—for example, are often used to distinguish between genera and between species within genera. Take the mustard family (Brassicaceae), which



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is quickly identifiable by their signature four-petaled flowers that are arranged in the shape of a cross, six stamens (four of one length and two of another) and characteristic fruits known as siliques or silicles. Morphological identification may focus more on the external features for animal groups like segmentation, appendage structure, integumentary and specialized organs. One large group of animals you won't hear about much are insects, and when it comes to them, wing venation patterns, mouthpart structure, and even antenna type are big diagnostic traits. Identification of vertebrates primarily relies on skeletal properties, dentition patterns, and external structures such as scale or feather structure[6]. The presence and arrangement of specific anatomical structures — from mammalian ear ossicles to insect spiracles — offer critical diagnostic clues.

Morphological characterization for the identification of microbes is considerably more complex but remains applicable, especially in the case of larger microorganisms such as protists and fungi. More general morphological markers include cell shape, colony morphology, and specialized structures such as flagella, cilia, or fruiting bodies. Identification of fungi is based on several features including types of spores and its mode of production of spores, hyphal organisation and structure of the fruiting body. Morphological identification tools and techniques go from the simple field observation to complex laboratory methods. Field identification usually depends on traits that can be used by sight, or with minimal magnification, and is done virtually entirely via field guides and dichotomous keys. Closer scrutiny may involve dissection, microscopy, or special stains to expose diagnostic characteristics. Thereafter, scanning electron microscopy (SEM) revolutionized morphological studies with highly magnified, three-dimensional images of surface structures not attainable by light microscopy; this is especially useful for small organisms or microstructures. Although historical, widely used, and often useful in practice, morphological identification is limited in many ways. Phenotypic plasticity — the capacity of a single genotype to generate distinct phenotypes as a function of environmental condition — can confound morphology-based identification. Morphological cryptic species—morphologically indistinguishable organisms that are genetically distinct—will go undetected in purely morphological approaches. Another complication is life stage variation; juvenile forms may differ strikingly from their adults, which require additional identification efforts. Morphological identification is complicated further by sexual dimorphism, seasonal variation, and physiogeographical variation within a species. Identifying species by morphology is a specialized expertise that is cultivated through years of training and experience. Taxonomists also develop an intuitive recognition ability sometimes referred to as the “taxonomic eye”—the



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ability to recognize subtle traits and tell significant differences from individual variation. This expertise is especially crucial for species-rich groups or for damaged or less than complete specimens.

Integrative taxonomy in this context emphasizes use of morphological identification in conjunction with molecular and other data sources as we continue to evolve modern taxonomic practice. This method incorporates the fact that these various forms of data offer complementary insights into biological variability. Morphological data can provide information about functional adaptations and read data that is not apparent in genetic sequences. In contrast, molecular data can uncover cryptic diversity and evolutionary relationships hidden behind convergence or plasticity. Novel technologies are augmenting classical morphological identification approaches. We therefore trained automated image recognition systems using artificial intelligence to help with species identification, traditional pixel classification methods still necessitate the use of large reference databases of correctly identified specimens (for more on this see Challenge Paper on Machine Learning and Image Analysis), these systems are therefore still limited by the reference dataset. Geometric morphometrics—the analysis of biological shape using landmark coordinates—offers a more objective route to the study of morphological variation. Non-destructive techniques such as micro-CT scanning allow for both analysis of internal structure and the generation of digital specimens that can be distributed worldwide. Morphological identification is still very much grounded in these reference collections, which are physical specimens that experts have identified and preserved in museums and herbaria (scientific collections of plants). These collections represent the final word in identification, offering solid evidence of the existence of species, both then and now. Digital collections, such as high-resolution images and 3D scans, are gradually augmenting physical collections and making reference material more broadly accessible.

3.3.1.3 Phenetic vs. Phylogenetic Classification

The history of biological classification can be characterized by a fundamental change of worldview and approach: The replacement of e.g. phenetic by phylogenetic approaches. Phenetic classification (numerical taxonomy/taximetrics) – initially arose in a big way in the 1950s and 1960s as an attempt to make taxonomy more objective and quantitative. In this way, it tells how similar or different organisms are to each other, using whatever observable features it can, and without making assumptions as to evolutionary significance. The general idea is that organisms that share a lot of features and characteristics are likely members of the same taxonomic group; this and others may have shared a common phylogenetic ancestor or may be the product of convergent evolutionary pathways. In phenetic classification, the



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weights of the characters are usually chosen to be equal, and sophisticated feature exchange statistics such as cannibalized cross-proximity slices are used to measure overall similarity indices in the organisms. These results of cluster analysis and ordination methods such as principal component analysis (PCA) or multidimensional scaling are used to visualize relationships and establish taxonomic limits. The resulting classifications are then often depicted as phenograms, tree-like diagrams representing degrees of affinity rather than of evolutionary relationship. When first introduced, phenetic approaches had several advantages. They offered a more straightforward, repeatable way of doing things than the sometimes intuitive traditional taxonomy. The explicit numerical methods permitted analysis of large matrices with numerous characters and taxa. Phenetic methods also made no assumptions about evolutionary processes or character polarity (which states are ancestral or derived), thus not requiring insight into evolution at the time of their application. From an evolutionary viewpoint, however, phenetic classification has serious limitations. Most importantly, unlike any successful scientific theory of evolution, it cannot discriminate between homology (similarity caused by descent from a common ancestor) and homoplasy (similarity caused by convergent evolution or parallel evolution). This suggests that phenetic relationships may be due to adaptive convergence rather than evolutionary relatedness. For example, sharks and dolphins have streamlined bodies, dorsal fins, and tail flukes due to their adaptation to an aquatic environment, but these similarities are convergent similarities, not similarities indicating that they are closely related.

Taxonomic classification, in contrast, aims to mirror evolutionary history and relationships between organisms. This method of classification, which Willi Hennig formalized as phylogenetic systematics, or cladistics, in the 1950s, only considers recency of common ancestry. The basic rule is that taxonomic groups are to be monophyletic—that is, including an ancestral species and all its descendants, comprising a complete branch of the tree of life. Phylogenetics deals with synapomorphies—homologous characters that occur at the same position within the genome but are derived after taxon divergence, suggesting shared ancestry. They are distinguished from symplesiomorphies (shared ancestral traits) and homoplasies (convergent similarities) via careful character analysis and outgroup comparison. This results in cladograms, or branching diagrams that represent hypothesized evolutionary relationships that reflect the distribution of derived character states. The phylogenetic approach to modern taxonomy has become dominant for several reasons: Most basically, it expresses the band of biology underlying evolution — the actual branching event of speciation and heritable change. Phylogenetic



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classifications are predictive — if we know something about one member of a clade, we can make predictions about properties among other members. They also offer the framework for comparative studies across disciplines — from ecology to physiology to development. This may have had significant consequences for taxonomy. Just like to mention, that this happened with many traditional taxonomic groups, that were either paraphyletic (containing some but not all descendants of a common ancestor) or polyphyletic (originating from two or more ancestral forms not common to all members of the group) were revised or even abandoned. Thus the traditional class "Reptilia" was a paraphyletic group that excluded birds, molecular and developmental data show to be nested in the reptile lineage as specialized dinosaurs. So too do "fish," which are a paraphyletic grouping, since tetrapods (humans included) came from lobe-finned fishes.

Modern phylogenetic methods use ever more complex analytical techniques. Parsimony methods find the tree with the least amount of evolutionary change required to explain observed character distributions. Maximum likelihood methods use probabilistic models of character evolution to find the tree that maximizes the probability of the observed data. The first, which shares some features with the familiar maximum-likelihood approach and builds one tree at a time, is contained within the realm of Bayesian inference, employing prior probability distributions in conjunction with observed data to derive posterior probabilities for alternative tree topologies. Early phylogenetic analyses were based mainly on morphological data, but the availability of molecular data has transformed the field. DNA and protein sequences offer thousands of characters for comparison, and these data sets frequently expound phylogenetic relationships that are obscured in morphological examination by convergence or the absence of visible characters. Yet despite the relevance of molecular data, it is not without its complications, such as mutations abound due to differences in mutation rates per gene, horizontal gene transfer and gene duplication events will lead to paralogous instead of orthologous gene sequences. The most powerful modern classifications utilize a multiplicity of data types — morphological, molecular, developmental, behavioral, ecological — in what are called total evidence approaches. Integrating multiple data types together allows researchers to overcome the limitations of any one data type and results in a more comprehensive picture of evolutionary relationships. The field has continued to develop with genomic approaches that allow entire genomes to be analyzed rather than selected genes, providing a level of resolution of evolutionary relationships that was unattainable in previous generations. Although phylogenetic classification is theoretically superior, practical considerations often force pragmatic compromises. There are still applications in which similarity in a



phenetic sense matters—for example, when drawing field guides and identification keys that rely on observable similarities as opposed to evolutionary ones. Some taxonomic groups can also still provide practical utility despite their phylogenetic placement being uncertain (with monophyly being questionable).

3.3.1.4 Taxonomic Keys (Dichotomous Keys)

Taxonomic keys provide accessible resources to facilitate the practical identification of species while integrating the scientific abstraction of taxonomy. Among these, dichotomous keys have proved especially useful, leading users along a structured path of binary yes/no choices until a correct identification is made. Key-based species identification simplifies the complex task of species recognition into a series of yes or no decisions regarding the observable characteristics of the organism. Each point in a dichotomous key consists of a set of contrasting statements through which a user can identify the correct state of a character. The user then looks at the specimen they are working with and decides which statement is true about it, going down the pathway indicated to the next set of couplets. This continues on a step by step basis until a terminal point is reached which gives a species identification. For example, a simple key for common deciduous trees might start with “1a. Leaves compound... go to 2” vs. “1b. Leaves simple... go to 5,” immediately separating the potential species into two big groups. There are two primary types of dichotomous keys, bracketed (or indented) and parallel. The structure of the bracketed keys is that the paired choices are presented together followed by options indented that indicate a nested visual representation of the choices, allowing users to see where they are in the key. The alternate design employed parallel keys, which list all couplets consecutively with each option redirecting users to the next number couplet, taking up less page space but occasionally making it difficult to continue tracking context through the key. There are several important design principles that determine the effectiveness of a dichotomous key: First, the alternative in each couplet must be mutually exclusive and collectively exhaustive, clearly contrasting the possibilities for the taxa in the key. The characters chosen should be consistently observable across specimens, somewhat stable across habitats and be able to be accessed using the tools planned to be available to the key’s users. Use technical terms sparingly and only when their meaning and relevance is explained clearly beforehand.

In well-made keys, the sequence of couplets is often strategic. Early couplets tend to use more tallies of more obvious characters, few of which are best seen in the same specimen, which splits the taxa into roughly equal groups and maximizes the information from the decision. Later couplets may utilize more specialized or technical characters as



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necessary to differentiate closely related taxa. This means there are less steps needed to reach an identification and less opportunity for errors to compound through the key. Dichotomous keys are devised for a variety of uses within a broad audience — general apparatus-specific technical keys for specialists versus exoculis for households such as amateur naturalists or students. Technical keys are descriptive and thorough, with a higher density of diagnostic characters including microscopic or anatomical ones, the observation of which requires special equipment. Field keys, by contrast, are focused on easily observable external features, and may include practical items such as seasonal availability, geographic range, or habitat preference to limit the options. Keys vary widely in their geographical and taxonomic scope. Some keys cover an entire taxonomic group in an entire region (e.g., all of the ferns of North America or all of the flowering plants of North America), while others are more tightly focused, covering (for example) an entire geographically restricted area (like the plants of a national park) or ecologically defined groups (such as the aquatic invertebrates in river running freshwater streams). Regional and local keys, although incomplete, often provide less cumbersome tools for appropriate field identification than more comprehensive works.

Inherent Limitations and Challenges Faced by Taxonomic Keys

Intraspecific variation — the differences between individuals in a species, due to age, sex, season or geography — can add up to ambiguity in key couplets. Keys should also allow for the possibility of damaged or incomplete specimens, and ideally include alternative routes based on different character sets. Additional complexities stem from environmental influences on morphology and from developmental transformations over an organism's life history. Recent developments in taxonomic keys aim to overcome these drawbacks. Multi-access keys (also known as polyclavate or synoptic keys) enable users to start with any character present, rather than follow a fixed sequence as is required in dichotomous keys, which is especially useful when some characters are absent or unobservable. Interactive electronic keys take this dynamic approach further, reformulating the most effective route to identification based on data you've entered. These digital tools may also include multimedia components such as high-resolution images, video clips of members of challenged behaviors, or interactive illustrations that explain more complex words. This automated identification is powered by the applications of the artificial intelligence and image processing technologies improving day by day. Mobile applications are available that analyze photographs to provide suggestions of potential identifications, but these often act to supplement traditional key-based approaches, especially for problem taxonomic groups that integrate specialist expert knowledge. Yet, despite great advances in technology, making effective taxonomic keys



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is still as much art as it is science. In many cases, key designers need to anticipate user challenges and possible pitfalls — and to write couplets in a way that makes people not confused. The best keys develop through extensive field testing with a mix of users, allowing it to be refined from the ground up.

Taxonomic keys can be seen as an intermediary data entry point in the wider taxonomic literature landscape. In doing this, they serve to point the reader towards more extensive monographs, floras and faunas that will include detailed descriptions, images, distribution records and ecological information. In contrast, keys prioritize the taxonomic characters that are most useful for diagnosis, and these essential ancillary resources provide the context for understanding the biology of the organism, its distribution and its evolutionary relationships. Taxonomic keys are an important applied taxonomic product that bring expert knowledge to impacted and non-taxonomic audiences. Well-designed keys (supported by high-quality images) allow non-specialists to accurately identify organisms and will assist fields from ecology and conservation (e.g., pest management) to agriculture, forestry, and public health. They are vital instruments for biodiversity assessment, environmental monitoring, invasive species detection and a host of other practical applications of taxonomic knowledge. Taxonomic keys present useful opportunities for developing observational skills and learning concepts of rules that guide taxonomical classification within the field of education. Working through a key reinforces careful observation and logical thinking with students and introduces them to the diversity of organisms and the traits that distinguish major groups. Constructing keys with simplified keys for familiar organisms has become a justified exercise in many biology programs exposing students to the challenges of biological classification and its theoretical basis.

3.3.2 Taxonomy, Identification, and Keys: An Introduction

Taxonomy, the science of cataloging living things, is one of biology's oldest disciplines, providing the framework for thinking and talking about biological diversity. The need for such systematic organization, which entails identifying and classifying systems and crops of diverse specialized literature, can be largely filled by identification methods. The activities of identification — establishing the taxonomic group an organism belongs to — and classification — creating a coherent system within those groups — are complementary activities that lie at the heart of biological science. The taxonomic hierarchy consists of successive categories of increasing specificity that reflect evolutionary relationships. This hierarchical classification system, which has been adapted over the centuries from Linnaeus's original framework, now includes domains at the range-topping level, working through



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kingdoms, phyla, classes, orders, families, and genera to the most particular level of species. Each level in this hierarchy is a hypothesis of evolutionary relatedness: Organisms within a group allegedly share a more recent common ancestor than they do with organisms from different groups. At the broadest taxonomic level, the domain level, all life is divided into three basic lineages: Bacteria, Archaea, and Eukarya. The three-domain system, which superseded the five-kingdom system based on the work of Carl Woese and ribosomal RNA sequences, better captures the ancient evolutionary history of all life on Earth. Perhaps the most important contribution of molecular taxonomy is the recognition that the two groups of prokaryotic organisms called Bacteria or prokaryotae, as well as the Archaea, once thought to be part of the same group, were distinct branches of the tree of life, since their biochemical and genetic make-up showed marked differences underlying the morphologically similar-appearing organisms. The kingdoms also represent major, distinct body plans and lineages, as well as life strategies, below the domain level.) Meanwhile, Eukarya includes the kingdoms of Animalia, Plantae, Fungi — mostly multicellular heterotrophs, multicellular photosynthetic organisms, and multicellular saprotrophic organisms with cell walls containing chitin — and many kingdoms of protists. The precise number, and definition, of kingdoms is somewhat elastic as molecular information has been sharpened our view of very deep evolutionary branches, especially among single-celled eukaryotes.

Phyla (or divisions in some botanical nomenclature) are only higher body plans within kingdoms. For example, in Animalia, the phyla Chordata, Arthropoda, Mollusca, and Echinodermata represent fundamentally different architectural strategies by which animals can be organized. So too with the plant divisions like Magnoliophyta (angiosperms), Pinophyta (conifers) and Bryophyta (mosses), these correspond to separate evolutionary lines with their own reproductive and vegetative traits. Classes further subdivide phyla into organisms with significant morphological and developmental differences. For example, within Chordata, classes such as Mammalia and Aves and Reptilia and Amphibia and many fish classes represent major vertebrate lineages with specific characteristics. Orders further subdivide classes by the nature of shared features, and families, a grouping of closely-related genera sharing recognizable morphological characteristics. Genera are made up of species that are closely related, and species—the basic unit of taxonomy—is theoretically defined as populations of organisms that can interbreed and produce fertile offspring in the wild, but this idea of a biological species concept has huge and very practical limitations and exceptions. Based on the external morphology, morphology-based identification including routine identification of organisms, identifying organs (by gross morphology) to tissues and



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cells (by microscopic morphology). Using comparative anatomy, histology, ultrastructure and patterns of development to determine groups of organisms and their placement in. The particular characters used vary widely between taxonomic groups, but usually consist of both external features that can be readily aperçu in the field, and further features that require dissection, microscopy, or special methods of preparation. Reproductive structures—flowers, fruits and seeds—will generally yield more reliable diagnostic characters (i.e. less environmentally plastic) than vegetative features. Floral formulae and diagrams are established notations or icons that give a standardized representation of flower structure that incorporates information on symmetry, fusion type, and numeric array of floral parts. These include vegetative characters such as leaf arrangement, venation patterns, stem anatomy, and specialized structures like stipules, which supplement reproductive characters and are particularly useful for identification in the absence of flowers or fruits.

The primary method with which animals and their relationships are identified is through external morphology—segments of the body, the structure of appendages, features of the covering—and internal anatomy as needed. For vertebrates, this can take the form of skeletal characteristics, dentition patterns, or specialized anatomical features that often give a definitive identification. Individual groups of invertebrates usually have their own specialized character sets, ranging from wing venation patterns in insects to spicule morphology in sponges. This is particularly true for microscopic organisms whose cellular organization and ultrastructure require more sophisticated techniques, such as multiple staining techniques. The advent of electron microscopy greatly increased the diversity of morphological characters available to taxonomy, exposing ultrastructural details unseen by light microscopy. Scanning electron microscopy (SEM) can provide high-resolution three-dimensional images of surface structures, while transmission electron microscopy (TEM) allows visualization of internal cellular architecture at the nanometer scale. These methods have been especially useful for microbial DNA taxonomy, delivering structural data from organisms that are simply too small to be investigated in any productive way with traditional microscopy. Morphological identification has some critical limitations despite its historical prevalence and current practical utility. Phenotypic plasticity, the ability of one genotype to produce various phenotypes depending on the environmental context, can introduce some ambiguity in morphological identification. Morphologically indistinguishable but reproductively isolated and genetically distinct organisms are called as Cryptic species and are ignored in purely morphological organisms. Confounding cross-life stage variation is another concern, with juvenile forms often looking radically different from adults requiring distinctive



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identification protocols. The choice between phenetic and phylogenetic methods of classification embodies one of the major paradigm shifts in taxonomic thought integral to modern systematics. This grouping of organisms based on overall similarity, without weighing the contribution of each character to evolutionary novelty (traits that are derived characters), was popular in the mid-20th century and was known as phenetic classification. This method, called numerical taxonomy, uses statistical techniques to compute indices of similarity and form groups of comparable groups. Phenograms—tree-like diagrams that show degrees of similarity represent the results of phenetic analysis, but may or may not reflect evolutionary relationships.

When they came onto the scene, phenetic approaches had a lot going for them. They offered a method more objective and more repeatable than sometimes intuitive traditional taxonomy. Because of the numerical methods being used explicitly, it was possible to handle large data sets of many characters and taxa. Moreover, phenetic approaches made no assumptions about evolutionary processes or about character polarity (the states that were ancestral or derived) and could thus be applied even when little was known about evolution. Phenetic classification is ultimately misguided, because it does not make the distinction between homology (similarity due to common ancestry) and homoplasy (similarity due to convergent or parallel evolution). The implication is that phenetic clades may be the result of adaptive convergence not evolutionary relatedness. For example marsupial and placental mammals with resembling ecological roles, or succulent plants of various families evolved to hostile, arid environments. Rather, these affinities are independent evolutionary responses to similar selective pressures and are not evidence of a close relationship. Phylogenetic classification, or cladistic taxonomy, is a radically different approach explicitly based on evolutionary history. This approach, outlined formally by Willi Hennig in the 1950s, sorts organisms according to recency of common ancestry alone, with a core principle that taxonomic groups should be monophyletic, including an ancestral species and all its descendents. The emphasis in phylogenetic analysis is on synapomorphies—derived, shared characters that indicate common ancestry—as opposed to symplesiomorphies (shared ancestral traits), which cannot be used to resolve relationships because they do not reflect more recent common ancestry and require rigorous character analysis and the use of outgroups to reveal differentiation. This change, from phenetic classification to phylogenetic classification has consequences that run very deep: snip snip. As a result of these works, many traditional taxonomic groups have been revised or discarded as paraphyletic (leaving out some descendants of the common ancestor) or polyphyletic (derived from multiple ancestral



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lineages). So it was, for example, that classical "Reptilia" omitted birds which molecular and developmental data show nested right in the middle of the reptile lineage as derived dinosaurs. In the same vein, "fish" are paraphyletic because tetrapods (a group covering us) are derived from lobe-finned fishes.

Always the source of trees, relatively limited to molecular data, phylogenetic classification pumped thousands of characters into the comparison process, often uncovering relationships that were obscured at the level of morphology. Nucleotide and protein sequences, while their own unique set of challenges including differing mutation rates, horizontal gene transfer, and gene duplications that lead to paralogous sequences, provide characters that are largely independent of ecological niche and adaptive convergence. Modern phylogenetic methods make use of ever more sophisticated analytical methods. Parsimony methods search for the tree that requires the minimal number of mutational changes to explain the distributions of observed characters. Maximum likelihood methods use models of character evolution to find the tree that maximizes the probability of observing the data. Bayesian inference combines prior probability distributions with observed data to generate posterior probabilities of alternative tree topologies. To facilitate identification, taxonomy practitioners utilize taxonomic keys that enable them to find and identify specimens; dichotomous keys are the most prevalent type of taxonomic key and have proven to be successful. These keys take users through a series of either-or questions based on observable traits, successively narrowing possibilities until arriving at a particular identification. A dichotomous key consists of a series of paired statements about contrasting alternative character states, with the user choosing the option for their specimen and following the path to the next decision point. Dichotomous keys need to balance several competing requirements to be effective. They need to be technically correct but also have to be easy enough for their intended users to understand. The chosen characters must be consistently observable, reasonably static across environmental variations, and attainable through the specific instruments available to the users of the key. If you must use technical terminology, define or demonstrate specialized terms. The framework should minimize the possible steps to get to an identification while allowing multiple pathways for when specific characters may not be available.

Various kinds of keys exist to meet diverse audiences and purposes. Technical keys for specialists might include microscopic or anatomical characters requiring specialized equipment while field keys highlight easily observed external features and may include practical steps such as seasonal availability or habitat preferences. Regional keys (presenting geographically limited areas as opposed to complete



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works) refer from the actual taxa existing in an area. After being used for centuries, scholarship on taxonomic keys developed to improve on the limitations of previous approaches. In multi-access keys, a user can start with any character that is present, unlike a sequential key where keys must be clicked in a specific order, which is beneficial when characters might be absent (in visible and observable space). Interactive electronic keys take the flexibility a step further, dynamically recomputing the most efficient route to identifying the individual for all of the entered data. These may include multimedia content like high-quality images, behavioral character video clips, or interactive illustrations explaining technical terms. Artificial intelligence and image recognition technologies open up new opportunities for automatic identification. Now there are mobile applications capable of analysing photographs for possibilities of identification, but these are generally used in addition to and not instead of traditional key-based methods, particularly with challenging groups that need the knowledge of experts. Taxonomic literature is an extremely broad and heterogeneous corpus of publications documenting, describing and organizing biological diversity. This repertoire is an interlinked web of resources that perform various roles in the taxonomic enterprise. Primary taxonomic literature—original descriptions, revisions and monographs—provides the primary documentation of biodiversity, while secondary literature—identification manuals, field guides and databases—widens this specialist knowledge. The most fundamental taxonomic publication is the formal description of new species. These descriptions establish new scientific names for the taxon following the rules and regulations set forth by nomenclatural codes (International Code of Zoological Nomenclature, International Code of Nomenclature for algae, fungi and plants, etc.) and include diagnostic information for recognition of the taxon. They usually contain a detailed morphological description, reaffirmation of the similarities with other species, information on geographical distribution and ecology and designation of the type specimens to serve permanent reference points to the name.

Taxonomic revisions reassess historically described taxa within a given group, often leading to synonymization of redundantly named entities, resurrection of previously synonymized names, or description of recently recognized species. Type specimens are reanalysed, character variation assessed across populations, and new data sources are used to more accurately resolve taxonomic limits. Vaughan, Richard D. *Food Sovereignty: Reconnecting Food, Nature and Community*. Kelsey Street Press. Comprehensive revisions, colloquially known as monographs, revise and encapsulate all of the information for entire taxonomic groups, compiling a new baseline for knowledge of the group's diversity and relationships. Regional taxonomic works—floras



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for plants and faunas for animals, documenting the species occurring in defined geographical areas from continents down to individual parks or preserves—are essential to managing human activity on the land. Such systematic works usually bear keys for identification, respectively description and distribution, as well as IUCN and ecology and ethnobiology data. Within their respective coverage areas, they are indispensable references for biodiversity research, conservation planning, and environmental impact assessment. The past few decades have seen the development of taxonomic databases and information systems to improve access to taxonomic information. Worldwide initiatives including the Catalogue of Life, Global Biodiversity Information Facility (GBIF), and Encyclopedia of Life compile and standardize taxonomic information and render it digitally accessible. Key Fields Specialized databases cater to specific groups, such as the genus *Cypripedium*, where you will find more detailed information (including interactive identification tools, distribution maps, and bibliographies) than ever. The taxonomic literature for any group is a highly interlinked web of publications accumulating over decades or centuries, with new works building on, correcting and adding to previous treatments. Navigating this literature requires an historical perspective of understanding how knowledge of a group has developed as well as an awareness of current agreement on classification and nomenclature. Specialized bibliographies and taxonomic indexing services trace the literature pertinent to certain taxa for researchers so that new found information and contributions are built on the appropriate prior work. Taxonomy's practical use goes well beyond documenting biodiversity as a scientific enterprise. Reliable identification is critical for the management of agricultural pests, detection of invasive species, diagnosis of disease vectors, identification of endangered species and many other applications in human health, food security and environmental management. The tools and literature of taxonomy—from specialist monographs to identification apps useful in the field—serve as an essential bridge between specialist knowledge and practical use.

Shaping future taxonomy by combining several approaches and data types Integrative taxonomy uses multiple lines of evidence from morphology, molecules, ecology, behavior, and geography to delimit species and reconstruct evolutionary relationships. Morphological characters that were inaccessible or hard to quantify are now being revealed through new imaging technologies, such as micro-CT scanning and confocal microscopy. Genomic approaches that survey entire genomes rather than selected genes offer unrivalled resolution of evolutionary relationships, whilst also uncovering the genetic basis of morphological adaptations. Most importantly, taxonomy is increasingly collaborative and open: international initiatives are



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coordinating effort across institutions and regions. Digital platforms allow specialists around the globe to collaborate in real time and citizen science projects involve non-professionals in documenting biodiversity. These trends are likely to speed taxonomic discovery and synthesis and provide taxonomy knowledge to great, public and scientific audiences.

Summary:

Identification is the process of **determining the correct name and position of an unknown plant** by comparing it with known plants or descriptions. It is the first step in taxonomy and helps place plants in their correct taxonomic rank.

Keys are **artificial devices used for rapid and accurate identification of plants** based on contrasting characters. They are mostly **dichotomous**, presenting two contrasting statements (couplets); selecting the correct one leads to further choices until the plant is identified. Keys may be of two main types:

- **Indented (Yoked) keys** – successive choices are indented.
- **Bracketed keys** – choices are numbered and referenced.

Multiple Choice Question(MCQs):

1. The process of assigning a plant to its correct name is called:
 - a) Classification
 - b) Identification
 - c) Nomenclature
 - d) Taxonomy

Ans: b) Identification
2. Keys used in plant identification are usually:
 - a) Random
 - b) Dichotomous
 - c) Numerical



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d) Phylogenetic

Ans: b) Dichotomous

3. Which of the following provides detailed description of plants of a particular area?

a) Index

b) Flora

c) Revision

d) Monograph

Ans: b) Flora

4. Index Kewensis is mainly used for:

a) Ecology

b) Nomenclature

c) Anatomy

d) Genetics

Ans: b) Nomenclature

5. The book that contains rules for naming plants is:

a) Flora of British India

b) ICN (International Code of Nomenclature)

c) Origin of Species

d) Species Plantarum

Ans: b) ICN (International Code of Nomenclature)

Short Answer Questions

1. Define identification in taxonomy.
2. What is a dichotomous key?
3. Differentiate between indented and bracketed keys.
4. Give two examples of taxonomic literature sources.
5. Mention any two types of floristic literature.

Long Answer Questions

1. Explain the process and importance of plant identification in taxonomy.



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2. Describe the types and structure of keys used in plant identification.
3. Write an account of different types of taxonomic literature and their significance.
4. Discuss the role of floras, monographs, and revisions in taxonomy.
5. Explain the use of indexing and nomenclatural resources in taxonomic studies.
6. Write an essay on the importance of keys and literature in plant systematics.

UNIT 3.4

Botanical nomenclature

Botanical nomenclature represents the formal system by which scientists name and classify plants. "Just like other fields of science where there's a very systematic way in which plants are named, this approach helps the botanists and horticulturists and scientists in general across the world communicate with each other despite all the differences in language or geographical location. For the sake of creating a framework to record botanical knowledge, allowing for research and an understanding of plant relationships, a standardized nomenclature system has been developed. Without it, botanical science would be waylaid by the confusion and miscommunication that arises when plants have widely varying regional common names — one species may be known by dozens of different names, depending on where one is and a plant might be commercially important in one region, but a nuisance in another.

Modern botanical nomenclature is based on the binomial system, which was developed by Carl Linnaeus in the 1700s. The common naming system is actually a radical innovation developed in 1753 and 1735 respectively by Swedish botanist Carl von Linnaeus, who has arguably been called the father of taxonomy. The established system in use is called binomial nomenclature, which as the name implies assigns two names to each plant species, a genus name followed by a specific epithet. This combination gives each species a unique identifier in the plant kingdom. The genus name, which is always capitalized, describes a group of closely related species that have a common set of characteristics. The second part of a scientific name is the specific epithet, written in lowercase and identifying a specific species within that genus. These two words together create the scientific name which is traditionally italicized or underlined in print. In *Quercus alba* (white oak), for example, *Quercus* is the genus name that includes all oaks, and *alba* is the specific epithet, identifying which particular oak species it is. There are many advantages to binomial nomenclature when compared with vernacular naming systems. First, it gives precision, by providing each plant species with a unique name that avoids the ambiguity of common names that may refer to multiple species. Second, it is taxonomic because it organizes the plant into taxonomic units that share evolutionary relationships, grouping them with other plants that a common ancestor placed within the same genus. Third, it provides stability based on internationally established rules for the creation and modification of names. Finally, it breaks down language barriers, using standardized Latin or Latinized names understood by scientists the world over.



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The binomial system also works in tandem with the concept of type specimens—preserved samples of a few examples of the plant to use as the final authority on what that name means. These specimens, stored in herbaria worldwide, offer the physical reference point that other plants are measured against during identification. When taxonomists discover a new species, they will designate one subclass member as holotype, which embodies the characteristics of that species and acts as its permanent reference point. A key rule in binomial nomenclature is the principle of priority, which asserts that the first validly published name for a particular taxon is the name that will be used officially for that taxon. This rule was designed to avoid the emergence of different scientific names for the same plant species. However, there are exceptions to this through conservation of names, where, in order to maintain nomenclatural stability, widely used names may be preserved even if they lack priority.

3.4.1 International Code of Nomenclature for Algae, Fungi, and Plants (ICNafp)

The International Code of Nomenclature for Algae, Fungi, and Plants (ICNafp), previously known as the International Code of Botanical Nomenclature (ICBN), is the exhaustive base that regulates the scientific name given to plants. This code embodies more than 150 years of international cooperation and improvement, which has continued to evolve as the issues in plant taxonomy and classification change. The ICNafp's roots date back to the mid-19th century when botanists mourned the absence of standards regarding naming conventions. The first complete rules were generated from the Paris Congress of 1867, and subsequent international botanical congresses have added to these guidelines. The current code is periodically amended at International Botanical Congresses (holding every 6 years or so) to keep it up to date as botanical science develops. The ICNafp is managed by the International Association for Plant Taxonomy (IAPT) and supervised by the Nomenclature Section of the International Botanical Congress. These bodies consider proposals for changes to the code and vote on amendments, keeping the code responsive to scientific advances and practical needs. The most recent substantial amendment was at the XIX International Botanical Congress (XIX IBC) held in Shenzhen, China, in 2017 when the Code's title was changed from International Code of Botanical Nomenclature to its current title (International Code of Nomenclature for algae, fungi, and plants) to also include algae and fungi as plants. The code is split into the principles, rules, recommendations, and appendices. The first section, the principles, enumerates the philosophical bases of botanical nomenclature, while the second section, the rules, prescribes the technical requirements for valid publication and name formation. Recommendations list best practices but carry no weighting;



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appendices contain additional information such as names conserved and names authors abbreviated.

The ICNafp has undergone one major evolution since its birth: it has adapted to electronic publishing. In 2011, the Melbourne Code took a significant step toward modern approaches to doing science by permitting the electronic publication of new names, which recognized the evolving nature of scientific dissemination. China's Regulations on the Protection of New Varieties of Plants (2016) were supplemented by the Shenzhen Code (2017), which acknowledged the growing significance of online botanical resources. Although the ICNafp operates separately, it is coordinated with other nomenclature codes for animals (International Code of Zoological Nomenclature), for bacteria (International Code of Nomenclature of Bacteria), and for cultivated plants (International Code of Nomenclature for Cultivated Plants). If both the BioIQ and GenomicView querying systems improve, they could complement each other and cover all biological organisms while being tailored to the respective discipline. One of the essential components of the ICNafp is a valid publication: (i) Publication (in a publicly available medium), (ii) a description of the materials, or a diagnosis, preferably in the English language, (iii) designation of a type specimen, and (iv) compliance with other technical criteria. The code also sets municipal January 1, 1753, the date of publication of Linnaeus's *Species Plantarum*, as the starting date for botanical nomenclature, with names published before this date having no standing. The ICNafp also deals with issues regarding taxonomic revisions. When taxonomists group two genera, split a genus, or reassign species, the code gives rules for which names should persist, and how new combinations must be created. This allows nomenclatural stability even though our understanding of plant relationships necessarily changes.

3.4.1.1 Principles and Rules

Botanical naming practices are based on six founding principles set forth by the International Code of Nomenclature for Algae, Fungi, and Plants. They serve as the philosophical foundations of the nomenclatural system and inform the interpretation and application of the more specific rules.

Principle 1: Independence from zoological nomenclature (The botanical nomenclature operates independently from zoological nomenclature; therefore, each system has its own rules, conventions, and infrastructure.) Plant systematics has the advantage of being relatively independent of the other fields outlined above, enabling specialized approaches informed by the unique features and taxonomic challenges of plant systematics itself. The second principle embodies



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the concept that nomenclature is based upon typification whereby all taxonomic names are permanently associated with a designated type specimen. This typification system thus serves as an objective reference point for name application; now scientists are able to determine exactly which population of plants a particular name should apply to, even if taxonomic concepts change. The third principle is Priority, and it holds that the validly published name of a taxon that is the oldest is accepted. Because of this principle, the same plant group cannot have a multitude of different names, which can be quite confusing, while it also provides a clear, objective way of solving competing names. The fourth principle contrasts with the third principle in that it requires that names be unique; that is to say, homonyms — a name used to denote more than one group of plants (at a specified taxonomic level) are forbidden. This mechanism guarantees that any name refers to one taxonomic unit, eliminating potential confusion in the field of science communication. Fifth, the scientific rather than vernacular aspect of botanical names. The Latinisation thus acts more as a mathematical or codical term of order than an attention to the nuances of etymology, treating all plant names as Latin, *abrazo*, which acts unifying by becoming language-agnostic, and dissociating itself from cultural specificity. The sixth principle accepts retroactivity: that is, a rule change applies all names, even ones published before the rule change was made, unless specifically excluded. This helps in the consistent implementation of nomenclatural standards in historical and modern botanical literature.

Beyond these principles, the ICNafp contains numerous specific rules governing the technical aspects of name formation and validity. These rules address issues such as:

1. Valid publication requirements, including publication in publicly available media, provision of a description or diagnosis, designation of a type specimen, and compliance with proper form.
2. Name formation rules, including correct Latin grammar and syntax, prohibition of excessively long names, and guidelines for forming names based on personal names, geographical locations, or other sources.
3. Author citation conventions, standardizing how to attribute the original publication of a name and subsequent taxonomic changes. For example, when a species is transferred to a new genus, the original author's name appears in parentheses followed by the name of the author who made the new combination.
4. Rules for handling nomenclatural conflicts, including procedures for conserving widely used names against strictly



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older ones (*nomina conservanda*), rejecting problematic names (*nomina rejicienda*), and establishing lists of protected names for economically important groups.

5. Provisions for nomenclatural types at different ranks, from the holotype specimen that defines a species to the type species that anchors a genus name and the type genus that grounds a family name.
6. Regulations governing the naming of hybrids, both naturally occurring and artificially created, using special notations such as the multiplication sign (×) to indicate hybrid status.
7. Rules for autonyms, which are automatically established names for subdivisions of genera and species that include the type of the next higher rank.

The code also contains numerous recommendations that, while not mandatory, represent best practices in botanical nomenclature. These include suggestions for choosing appropriate etymologies for new names, avoiding potentially confusing names, and following standardized abbreviations for author names.

3.4.1.2 Taxonomic Ranks

Taxonomic Ranks in Botany Nomenclature Taxonomic ranks in botany nomenclature is the hierarchical structure that is employed for plant classification. The ICNafp regulates the naming of plants but does not control the assignment of plants to particular ranks, which is a taxonomic judgment based on scientific evidence. (from most inclusive to most specific) the principal ranks recognized in botanical nomenclature: kingdom, division (or phylum), class, order, family, genus, and species. A taxon at the next lower rank is included within each rank in a hierarchy that is nested. A family is a related genera, a genus is a related species, etc. This tree-like framework is a reflection of how plant lineages diverged throughout the history of life. Plant kingdom *Plantae* was traditionally used to refer to all plants, but modern classification has spread photosynthetic organisms over several kingdoms for greater reflection of evolutionary relationships. All green plants are now usually placed in the kingdom *Plantae*, whereas the algal groups are assigned in other kingdoms based on their independent evolutionary histories. There are many such divisions that represent major evolutionary lineages within the plant kingdom (which are also known as phyla). Principal divisions of plants are *Bryophyta* (mosses), *Pteridophyta* (ferns and their relatives), *Pinophyta* (conifers), and *Magnoliophyta* (flowering plants). Division names generally also end with the suffix *-phyta*. Advancements in molecular systematics have clarified traditional divisions as better representing evolutionary



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kinship and clades formerly identified as divisions but now covering entities with no formal ranks.

Classes are major groupings within divisions (chordates, for instance) and end with the suffix “-opsida” in the case of plants. For example, within flowering plants, Liliopsida (monocotyledons) and Magnoliopsida (dicotyledons) are traditional classes, but modern taxonomy has reorganized classes based on genetic evidence. Orders are groups of related families and generally end in “-ales.” Some other examples are Rosales (roses, elms and corvettes), Poales (grasses, sedges and corvettes), and Asterales (sunflowers, daisies and corvettes). Orders have been ordered essentially on the basis of the molecular phylogenetic studies carried out, leading in some cases to the splitting, and in others, of classical orders. Families are a particularly far-reaching rank in practical plant taxonomy, despite being only slightly higher than the species within the taxonomic hierarchy and are groups of nominative and related genera that basically share common morphological traits. A family name often ends with the suffix “-aceae,” for example, the family of sunflowers is called Asteraceae, the grass family is Poaceae, and the rose family is Rosaceae. Some of the families that have traditional names (for example, Compositae, Gramineae, and Leguminosae) may be used as alternatives to their respective “-aceae” names. The genus is a group of closely related species with high morphological and genetic similarity. Genus names are singular nouns in Latin form, and are always capitalized. Examples of such genera includes *Quercus* (oaks), *Rosa* (roses), and *Solanum* (nightshades, including potatoes and tomatoes). Taxonomic refinement can result in splitting a because widely applied and assisting in generic concepts, and sometimes more genera are merged into a generic concept.

The species is the basic unit of taxonomy and was originally meant to correspond to a population of interbreeding organisms with a common gene pool and similar attributes. Species names are binomials: the genus name followed by the specific epithet, as in *Quercus alba* (white oak) or *Rosa canina* (dog rose). Botanical nomenclature also affirms side ranks that deliver even higher levels of hierarchy. Intermediate ranks may be inserted between the principal ranks, e.g. subkingdom, superorder, subfamily. When established, ranks within a species are called infraspecific ranks, such as subspecies, variety, and form, and they allow taxonomists to formally recognize significant variation within species. All of these ranks are subject to nomenclatural patterns defined in the ICNafp. Two classifications hold in botany: the traditional, Linnaean-type, hierarchical approach and the more modern phylogenetic nomenclature that more closely adheres to the taxonomic rank system. Although a Linnaean hierarchy is a familiar framework, in the modern age increasingly plant systematics works towards



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defining monophyletic groups (clades) using molecular phylogenetic analysis. The lower ranks have also many newly discovered clades that don't have ranks but are recognised and lead to a more detailed but evolutionarily correct evolutionary classification. The most modern family arrangement in clades of flowering plant is that of the Angiosperm Phylogeny Group (APG), which is an example of a modern flowering plant classification with the ranks that are used being used judiciously mainly at the order and family level, with most clades left unranked. Now in its fourth edition (APG IV), this system has not only been well accepted but mirrors evolutionary relationships supported by molecular data. Taxonomic ranks are associated with nomenclatural implications because the ICNafp underlines certain rules governing the naming of taxa at different ranks. For expanding on, family names must end in “-aceae” (with a small number also authorized exceptions), and order names need to conclusion in “-ales”; and class names commonly conclusion in “-opsida” for plants. Such standardized endings enable quick recognition by botanists of the rank of a taxon from its name.

Summary

The ranking of a plant group, and its assignment, is thus a judgment call determined by the relative morphology of the plant group, relative genetic divergence, relative evolutionary advancement, and utility. The reason why different taxonomic treatments assign the same plant group's taxonomic rank differently can be attributed to this subjectivity. For example, a taxonomist who treats a group as a family may treat it as a subfamily when weighing other biological and practical data. This subjectivity notwithstanding, taxonomic ranks do serve important practical purposes. They offer a vocabulary for discussing plant diversity at various levels of inclusiveness, assist in the organization of botanical information in floras and databases and help convey the degrees of relatedness among groups of plants. Because of this hierarchical system it also makes it easier to identify as a user can filter down from broader categories to more specific categories.

SELF ASSESSMENT QUESTIONS

Multiple Choice Questions (MCQs):

1. In which geological period did angiosperms first appear?
 - a) Jurassic
 - b) Triassic
 - c) Cretaceous
 - d) Devonian

Ans. c) Cretaceous



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2. Which of the following is considered a primitive angiosperm?
- a) Magnolia
 - b) Oak
 - c) Wheat
 - d) Pine

Ans. a) Magnolia

3. Angiosperms are primarily distinguished from gymnosperms by:
- a) Presence of cones
 - b) Production of flowers and enclosed seeds
 - c) Absence of vascular tissue
 - d) Lack of true roots

Ans. b) Production of flowers and enclosed seeds

4. What is the main aim of angiosperm taxonomy?
- a) To classify plants based on color
 - b) To establish a systematic framework for plant relationships
 - c) To study only extinct plants
 - d) To determine plant growth rate

Ans. b) To establish a systematic framework for plant relationships

5. Which classification method uses evolutionary relationships among species?
- a) Artificial classification
 - b) Phenetic classification
 - c) Phylogenetic classification
 - d) Random classification

Ans. c) Phylogenetic classification

6. The taxonomic key that uses a stepwise choice between two contrasting statements is called:
- a) Morphological key
 - b) Phenetic key
 - c) Dichotomous key
 - d) Genetic key

Ans. c) Dichotomous key

7. The system of binomial nomenclature was introduced by:
- a) Aristotle
 - b) Carl Linnaeus
 - c) Charles Darwin
 - d) Gregor Mendel

Ans. b) Carl Linnaeus



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8. The International Code of Nomenclature for Algae, Fungi, and Plants (ICNafp) governs:
- a) Classification of animals
 - b) Naming of bacterial species
 - c) Naming and classification of plants
 - d) Identification of viruses

Ans. c) Naming and classification of plants

9. What is the correct taxonomic rank order?
- a) Order → Class → Family → Genus
 - b) Family → Class → Order → Genus
 - c) Class → Order → Family → Genus
 - d) Genus → Order → Class → Family

Ans. c) Class → Order → Family → Genus

10. Which of the following is NOT a principle of botanical nomenclature?
- a) Each plant should have multiple scientific names
 - b) Scientific names are Latinized
 - c) Priority of publication is followed
 - d) Each species has a unique binomial name

Ans. a) Each plant should have multiple scientific names

Short Answer Questions:

1. Define angiosperms and mention their key characteristics.
2. What are some primitive angiosperms? Give examples.
3. How did angiosperms evolve from early seed plants?
4. What are the fundamental components of angiosperm taxonomy?
5. Differentiate between phenetic and phylogenetic classification.
6. What are taxonomic keys, and how are they useful?
7. Explain the principle of binomial nomenclature.
8. What is the purpose of the International Code of Nomenclature (ICNafp)?
9. Define taxonomic hierarchy and mention its ranks.
10. What is the importance of taxonomic literature in plant identification?



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Long Answer Questions:

1. Explain the origin and evolution of angiosperms with reference to fossil evidence.
2. Discuss the evolutionary adaptations that led to the success of angiosperms.
3. What is the role of genetics and molecular evolution in understanding angiosperm diversification?
4. Describe the major aims and components of angiosperm taxonomy.
5. Compare and contrast different classification methods in plant taxonomy.
6. Explain the process of plant identification using dichotomous keys.
7. Discuss the importance of botanical nomenclature and the role of ICNafp.
8. What are taxonomic ranks? Describe their significance in plant classification.
9. Explain the impact of extinction events on early angiosperms and their survival strategies.
10. Provide a detailed account of the differences between primitive and modern angiosperms.

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MODULE -4

CLASSIFICATION OF ANGIOSPERMS

4.0 Objectives

- Understand the classification systems of angiosperms proposed by Bentham & Hooker and Engler & Prantl.
- Learn about the merits and demerits of different classification systems.
- Explore the role of cytology in plant taxonomy.
- Understand the significance of phytochemistry in plant classification and medicinal plant identification.

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UNIT 4.1

4.1.1 Salient features of the systems proposed by Bentham and Hooker

The **system of classification proposed by George Bentham and Joseph Dalton Hooker** is one of the most practical and widely used **natural systems of classification of angiosperms**. It was published in their monumental work *Genera Plantarum* (1862–1883), where they described all known genera of flowering plants at that time. This system is highly regarded because it was based on **actual examination of specimens** rather than theoretical assumptions, making it a practical tool for identification in herbaria and botanical gardens.

Bentham and Hooker classified only **angiosperms (flowering plants)** and divided them into three major classes: **Dicotyledones**, **Gymnospermae**, and **Monocotyledones**. Among these, dicots were further divided into three series **Polypetalae**, **Gamopetalae**, and **Monochlamydeae** based mainly on the nature of the floral whorls, especially the petals. Each series was then subdivided into **orders (now called families)** and further into **genera and species**. A remarkable feature of this system was its **natural approach**: Bentham and Hooker considered a wide range of characters, including morphology of leaves, flowers, androecium, gynoecium, fruit, and seed structure, to group plants with true affinities together.

Another salient feature is that they placed **Gymnosperms between dicots and monocots**, treating them as a separate class, which reflected the understanding of their time. Despite later changes in phylogenetic insights, this system remains valuable because of its clarity, detailed descriptions, and ease of use. It is **not phylogenetic** it does not show evolutionary relationships but it is **practical and natural**, widely



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adopted in floras, herbaria, and teaching. Its hierarchy of *Class* → *Series* → *Order* → *Family* → *Genus* → *Species* set a benchmark for systematic botany, and even today many families retain the delimitations defined by Bentham and Hooker.

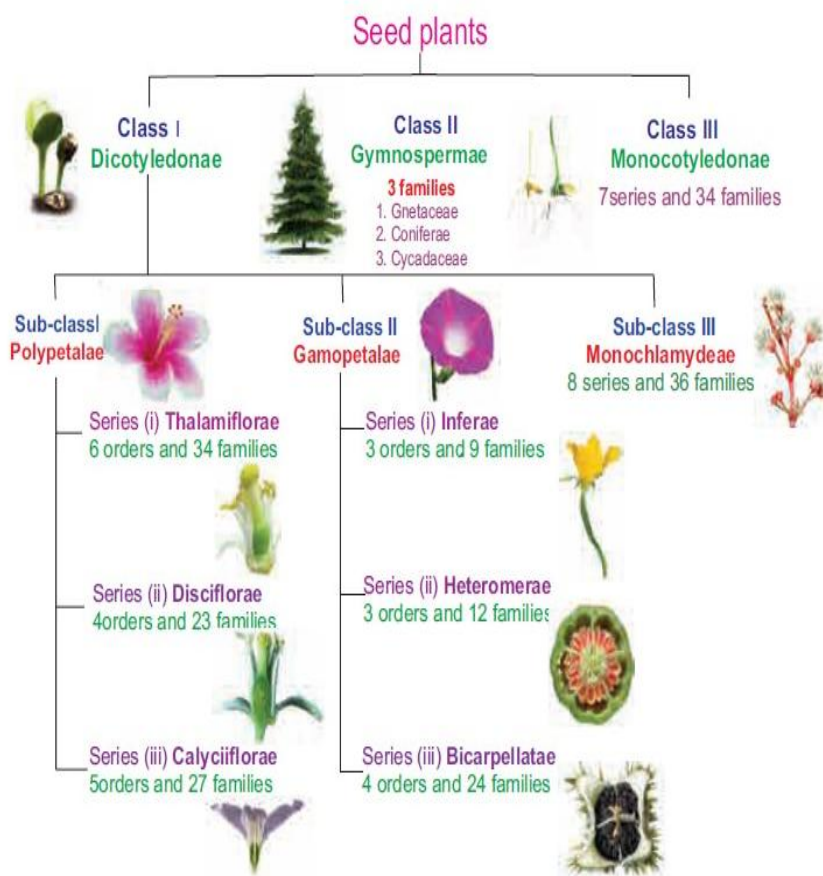


Fig. 4.1 The system of classification proposed by George Bentham and Joseph Dalton Hooker

In this system the seeded plants were classified into 3 major classes such as Dicotyledonae, Gymnospermae and Monocotyledonae.

Class I Dicotyledonae: Plants contain two cotyledons in their seed, leaves with reticulate venation, tap root system and tetramerous or pentamerous flowers come under this class. It includes three sub-classes – **Polypetalae**, **Gamopetalae** and **Monochlamydeae**.

Sub-class 1. Polypetalae: Plants with free petals and dichlamydeous flowers come under polypetalae. It is further divided into three series – **Thalamiflorae**, **Disciflorae** and **Calyciflorae**.

Series (i) Thalamiflorae: Plants having flowers with dome or conical shaped thalamus and superior ovary are included in this series. It includes 6 orders and 34 families.



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Series (ii) Disciflorae: Flowers having prominent disc shaped thalamus with superior ovary come under this series. It includes 4 orders and 23 families.

Series (iii) Calyciflorae: It includes plants having flowers with cup shaped thalamus and with inferior or sometimes with half inferior ovary. Calyciflorae includes 5 orders and 27 families.

Sub-class 2. Gamopetalae: Plants with united petals, which are either partially or completely fused to one another and dichlamydeous are placed under Gamopetalae. It is further divided into three series – Inferae, Heteromerae and Bicarpellatae.

Series (i) Inferae: The flowers are epigynous and with inferior ovary. Inferae includes 3 orders and 9 families.

Series (ii) Heteromerae: The flowers are hypogynous, superior ovary and with more than two carpels. Heteromerae includes 3 orders and 12 families.

Series (iii) Bicarpellatae: The flowers are hypogynous, superior ovary and with two carpels. Bicarpellatae includes 4 orders and 24 families.

Sub-class 3. Monochlamydeae: Plants with incomplete flowers either apetalous or with undifferentiated calyx and corolla are placed under Monochlamydeae. The sepals and petals are not distinguished and they are called **perianth**. Sometimes both the whorls are absent. Monochlamydeae includes 8 series and 36 families.

Class II Gymnospermae: Plants that contain naked seeds come under this class. Gymnospermae includes three families – Gnetaceae, Coniferae and Cycadaceae.

Class III Monocotyledonae: Plants contain only one cotyledon in their seed, leaves with parallel venation, fibrous root system and trimerous flowers come under this class. The Monocotyledonae has 7 series and 34 families.

4.1.1.1 Merits of Bentham's and Hooker's System

- **Natural system:** Based on a wide range of morphological characters (flowers, leaves, stems, seeds) rather than a single feature.
- **Practical approach:** Developed from the direct study of herbarium specimens from all over the world.
- **Clear hierarchy:** Simple and logical arrangement – Class → Series → Order (Family) → Genus → Species.



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- **User-friendly:** Easy to understand and apply for plant identification in herbaria, floras, and field work.
- **Well-defined families:** Many families and genera described are still accepted in modern taxonomy.
- **Widely adopted:** Used as a standard reference in many botanical gardens and institutions.
- **Bridge between systems:** Serves as a link between older artificial systems and later phylogenetic systems.
- **Stability:** Provides a stable foundation for plant classification for more than a century.

4.1.1.2 Demerits of Bentham's and Hooker's System

- **Not phylogenetic:**
Does not show evolutionary relationships; based only on overall similarity.
- **Gymnosperms misplaced:**
Treated as a class between dicots and monocots, which is not evolutionarily accurate.
- **Monochlamydeae artificial grouping:**
Plants with reduced or absent perianth were grouped together even though they are unrelated.
- **No modern data used:**
Lacks information from cytology, embryology, genetics, and molecular studies (unknown at that time).
- **Not reflecting natural ancestry:**
Some unrelated families appear close together due to reliance on morphological characters only.

Summary:

Bentham and Hooker proposed one of the **most widely used natural classification systems of angiosperms** in their book “**Genera Plantarum**” (1862–1883). They classified about **97,205 species in 202 families** of seed plants. Their system is **practical, based mainly on morphological characters**, and is especially useful for the **identification of plants in herbaria and field work**.

- It is a **natural system of classification**, based on overall morphological similarities.



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- It deals only with **seed plants (phanerogams)** —
Gymnosperms and Angiosperms.
- **Angiosperms are divided into three classes:**
 1. **Dicotyledons** – with 3 subclasses: Polypetalae,
Gamopetalae, Monochlamydeae.
 2. **Gymnospermae**
 3. **Monocotyledons**

Multiple Choice Question (MCQs):

1. Bentham and Hooker's system of classification is:
 - a) Artificial
 - b) Natural
 - c) Phylogenetic
 - d) Numerical

Ans: b) Natural

2. The book "Genera Plantarum" was written by:
 - a) Linnaeus
 - b) Engler and Prantl
 - c) Bentham and Hooker
 - d) Takhtajan

Ans: c) Bentham and Hooker

3. Which group was **not** included by Bentham and Hooker in their system?
 - a) Gymnosperms
 - b) Bryophytes
 - c) Monocots
 - d) Dicots

Ans: b) Bryophytes

4. How many classes of angiosperms are recognised in this system?
 - a) Two
 - b) Three
 - c) Four



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d) Five

Ans: b) Three (Dicots, Gymnosperms, Monocots)

5. Which of the following is a subclass of dicots in their system?

a) Polypetalae

b) Liliatae

c) Graminae

d) Coniferae

Ans: a) Polypetalae

Short Answer Questions

1. What type of classification system was proposed by Bentham and Hooker?
2. Name the book in which Bentham and Hooker published their system.
3. Mention the three classes recognized by Bentham and Hooker.
4. Name the three subclasses of dicots in their system.
5. Write one major limitation of Bentham and Hooker's system.
6. What is the main basis of their classification?

Long Answer Questions

1. Describe the salient features of Bentham and Hooker's system of classification.
2. Explain the hierarchical arrangement of angiosperms according to Bentham and Hooker.
3. Write an account of the three subclasses of dicots as given by Bentham and Hooker.
4. Discuss the merits and demerits of Bentham and Hooker's system.
5. Compare Bentham and Hooker's system with any one phylogenetic system.
6. Write an essay on the importance of Bentham and Hooker's classification in modern taxonomy.



UNIT 4.2

Engler and Prantl System of Classification

The Engler and Prantl system of classification represents one of the most influential taxonomic frameworks in the history of plant systematics. Developed in the late 19th century by German botanists Adolf Engler and Karl Prantl, this system represented a major advancement in the organization of plant diversity, moving beyond earlier systems by incorporating evolutionary concepts while maintaining a practical approach to plant identification and arrangement.

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4.2.1 Classification Systems

In the Engler and Prantl system of 1887 the entire plant kingdom was classified into thirteen divisions, which can be understood as a ladder of increasing complexity. This thorough categorization laid the groundwork for botanical investigations for centuries to come. The whole solitaire started with the first division: Division I: Myxothallophyta (slime molds): plants which were placed separately from trues ones at that time (but now belong to protists). These simplest so-called "plant-like" organisms were already at the beginning of their evolutionary sequence. Division II in their system was Schizophyta, i.e. bacteria and blue-green algae (today found under the classification of cyanobacteria). So in those times these groups ended up in one of two kingdoms, while scientists now recognize them as members of vastly different kingdoms. Division III: Flagellatae: This division's classification is very confused, as many of the organisms have features that are both plant-like and animal-like. This group, along with some other early-dividing groups in the next four divisions, are no longer placed in the plant kingdom in modern classifications. Division IV was Dinoflagellatae (dinoflagellates), and Division V: Bacillariales (diatoms), these two taxa (mainly marine photosynthetic organisms) are no longer considered plants, but are classified with protoctista instead of plants. Then were classified Division VI: Conjugatae (conjugating green algae), Division VII: Chlorophyceae (green algae), Division VIII: Characeae (stoneworts), Division IX: Phaeophyceae (brown algae), Division X: Rhodophyceae (red algae). However, in the Engler and Prantl system, there was a great deal of attention paid to these various algal groups, which were each given separate divisions (or classes) within the flowering plant system. Division XI, the Eumycetes (true fungi): now in a separate kingdom, these were plant animals in 1890. This shows even more how comprehensive the system was of all organisms that had been studied by botanists in that period. Thus, Division XII covered the



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Embryophyta Asiphonogama, including bryophytes (mosses, liverworts and hornworts) and pteridophytes (ferns and their allies). In their evolutionary progression, these groups were the transition between predominantly aquatic and predominantly terrestrial vegetative forms. At last, there is Division XIII, the Embryophyta Siphonogama, which involves all the plants that give seeds. This division in turn was split into two substantial subdivisions: Gymnospermae (gymnosperms) and Angiospermae (angiosperms), which indicated the elementary separation between plants that produced bare seeds (gymnosperms) versus those that produced seeds enclosed in fruits (angiosperms).

These included, the seed ferns (now extinct, in the class Cycadofilicales), the cycads (the class Cycadales), another extinct group (the class Bennettitales), two living groups (the class Ginkgoales, represented by the single living species *Ginkgo biloba*, and the class Coniferae, the conifers), and finally a small group comprising Gnetum, Ephedra, and Welwitschia (the class Gnetales). Angiospermae, the flowering plants, were divided into two classes, Monocotyledoneae (monocots) and Dicotyledoneae (dicots). This division, derived primarily on the number of cotyledons (seed leaves), was arguably the most rigid facet of their hierarchization, but now classifications have refined this classical division. The sequence went from the most primitive families (with simple flowers and free floral parts) to the more advanced forms. The Dicotyledoneae were arranged in what was thought to be an evolutionary sequence as well. This class had two subclasses, the Archichlamydeae (that have free petals or no petals) and the Metachlamydeae or Sympetalae (with petals fused). This division was based on the perception that the fusion of floral elements was an evolutionary step forward. The system worked from the more primitive families (families with simple flowers that lack differentiated perianth) towards more complex forms within the Archichlamydeae. The major orders were Verticillatae, Piperales, Juglandales, Fagales, Urticales, Proteales, Santalales, Aristolochiales, Polygonales, Centrospermae, Ranales, Rhoeadales, Sarraceniales, Rosales, Geraniales, Sapindales, Rhamnales, Malvales, Parietales, Opuntiales, Myrtiflorae, and Umbelliflorae. The Metachlamydeae (Sympetalae) were what you would classify as the most highly evolved dicots, complete; petals were all fused. The higher orders were Ericales, Primulales, Ebenales, Contortae, Tubiflorae, Plantaginales, Rubiales, Campanulales, and Asterales, Asteraceae (Compositae) being the highest family. Although this orderly display of plant groups represented the state of botanical knowledge at the turn of the 20th century, this establishment of a framework would be influential in plant systematics for decades even as new information, and new approaches, would soon bring about its widespread revision.

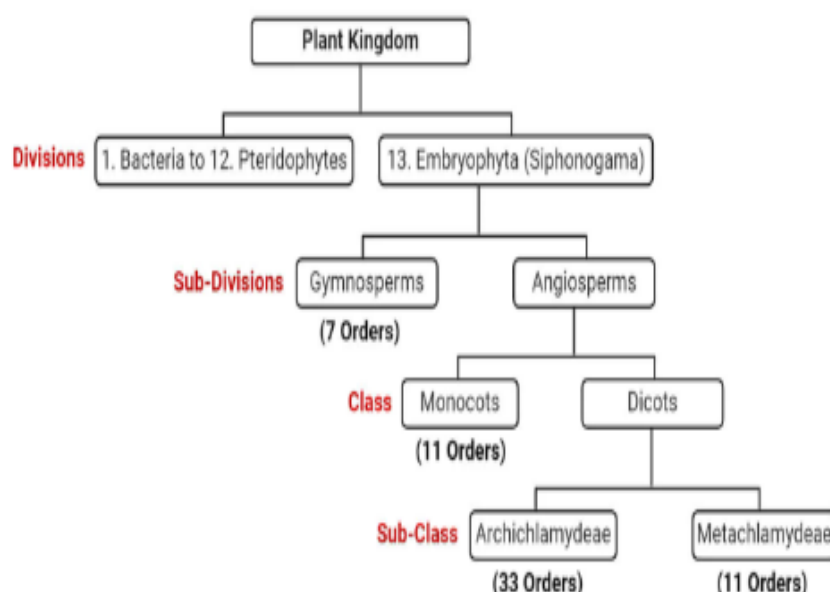


Fig.4.2 The system of classification proposed by George Bentham and Joseph Dalton Hooker

4.2.1.1 Merits and Demerits

1. Phylogenetic approach

- This was among the earliest systems that tried to arrange plants on a *phylogenetic basis* (according to evolutionary relationships) rather than only on morphological similarity.

2. Recognition of Monocots as primitive

- Engler considered *monocotyledons* as more primitive than dicots (based on simplicity of floral structures), which was a significant step in evolutionary thinking.

3. Importance of simple flowers

- Plants with *simple, unisexual and wind-pollinated flowers* (e.g., Amentiferae) were placed near the base of the dicot series, reflecting the idea of gradual complexity.

4. Extensive and detailed

- It covered almost all known genera of flowering plants of that time and was very comprehensive.

5. Foundation for many future works



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- His arrangement influenced many later taxonomic treatments and provided a starting point for further refinement.

4.2.1.2 Demerits of Engler & Prantl's System

1. Monocots as primitive is now rejected

- Modern evidence shows *monocotyledons evolved from dicots*, so placing monocots before dicots is incorrect.

2. Amentiferae treated as primitive

- Groups with reduced flowers (e.g., catkin-bearing plants) were considered primitive, but modern studies show they are *highly evolved and reduced* forms, not primitive.

3. Artificial treatment in some parts

- Certain related families were widely separated or grouped without sufficient evolutionary evidence.

4. Overemphasis on floral simplicity

- The assumption that simple flowers are always primitive ignores cases where simplicity is due to reduction, not primitiveness.

5. Incomplete phylogenetic knowledge at the time

- Because molecular and fossil evidence was lacking, many evolutionary relationships proposed by Engler & Prantl are now considered inaccurate.

Summary:

The Engler and Prantl system, proposed by Adolf Engler and Karl Prantl in their monumental work "**Die Natürlichen Pflanzenfamilien**" (1887–1915), is a **phylogenetic system** based mainly on **morphological and evolutionary relationships** among plants. They arranged plants in an **ascending evolutionary order**, starting from the **simplest thallophytes (algae, fungi, lichens)** to the most **complex angiosperms (dicots and monocots)**. They considered **absence of perianth and unisexual flowers as primitive** and **bisexual flowers with perianth as advanced**, which led to placing **monocots before dicots** and **Amentiferae (catkin-bearing families) as primitive among dicots**. This view is now considered **artificial** as modern evidence shows bisexual flowers are more primitive.



Multiple Choice Question (MCQs):

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1. Who proposed the Engler and Prantl system of classification?

- a) Bentham and Hooker
- b) Linnaeus
- c) Engler and Prantl
- d) Hutchinson

Answer : c) Engler and Prantl

2. In which year was the Engler and Prantl system first published?

- a) 1753
- b) 1887
- c) 1862
- d) 1968

Answer : b) 1887

3. What is the name of their publication?

- a) Genera Plantarum
- b) Die Natürlichen Pflanzenfamilien
- c) Species Plantarum
- d) Origin of Species

Answer : b) Die Natürlichen Pflanzenfamilien

4. Which type of classification is the Engler and Prantl system?

- a) Artificial



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- b) Natural
- c) Phylogenetic
- d) Numerical

Answer: c) Phylogenetic

5. Which plants were placed before dicots in their system?

- a) Gymnosperms
- b) Monocots
- c) Pteridophytes
- d) Bryophytes

Answer: b) Monocots

Short Answer Questions

1. Mention the names of the scientists who proposed the Engler and Prantl system.
2. What was the main principle behind their classification?
3. Why were monocots placed before dicots in their system?
4. Write the name of their major publication.
5. State one major drawback of the Engler and Prantl system.

Long Answer Questions

1. Describe the salient features of the Engler and Prantl system of classification.
2. Explain how Engler and Prantl arranged angiosperms and the basis for their sequence.
3. Compare the Engler and Prantl system with Bentham and Hooker's system.

4. Critically evaluate the merits and demerits of the Engler and Prantl system.
5. Discuss the phylogenetic assumptions made by Engler and Prantl about floral evolution and their modern status.



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UNIT 4.3

4.3.1 Major contributions of cytology, taxonomy.

The intertwined disciplines of cytology and taxonomy have fundamentally shaped our understanding of biological diversity and evolutionary relationships. Cytology, the study of cells and their structures, particularly chromosomes, has provided crucial insights into the genetic basis of taxonomy, the science of biological classification. Together, these fields have revolutionized how we identify, categorize, and understand the relationships between organisms, offering powerful tools for revealing evolutionary patterns and mechanisms.

4.3.1.1 Cytology and Taxonomy: Historical Development and Integration

With improvements in microscope technology, cytology became a scientific discipline in the 19th century, leading to revolutionary discoveries about cellular structure. In 1831, Robert Brown discovered the nucleus, and in 1882 Walther Flemming defined chromosomes; the groundwork for cellular organization was established. These findings were contemporaneous with major advances in taxonomy, which had progressed from Aristotle's basic categorizations to the binomial nomenclature established by Carl Linnaeus in the 18th century. The incorporation of cytological data into taxonomic practice dates back to the early 20th century, when scientists began to draw the conclusion that features of the chromosomes could be helpful in classification. The result for cytotaxonomy, a new approach using features of chromosomes to help make decisions about taxonomy. This integration was of great theoretical significance, and became readily apparent with the development of the Modern Synthesis in evolutionary biology, which unified Mendelian genetics with Darwinian natural selection, to provide a theoretical framework capable of explaining the mechanism of inheritance through genes while also explaining speciation based on changes in gene frequencies in populations over time. Taxonomists were gradually provided with increasingly detailed information regarding chromosomal structures and variations, as cytological techniques grew more sophisticated during the 20th century, ranging from basic staining techniques to advanced molecular ones. Such an enormous wealth of data has markedly improved our capacity to reconstruct evolutionary relationships, especially in clades where traditional morphology failed to resolve phylogenies satisfactorily.



4.3.1.2 Evolutionary Implications and Taxonomic Usage of Chromosome Number

The realization that each species has a characteristic number of chromosomes was a watershed in biological science. This numerical cyclicity within species with differences across species provided taxonomists a robust new way to classify organisms. The Cultural Evolution of Chromosome Numbers: Patterns with Phylogenetic Implications The study of chromosome numbers has revealed many patterns, some of which have proven useful in understanding evolutionary relationships and mechanisms. One of the most prominent discoveries was about polyploidy, which refers to the existence of more than two complete sets of chromosomes; this phenomenon has been by far the most prominent mechanism for speciation, and has played an important role in the evolution of plants. Polyploidy has been confirmed to contribute to plant diversity and evolution, with about 70% of angiosperms having polyploid origins. For example, the wheat genus *Triticum* presents a split between diploid (*T. monococcum*, $2n=14$) and hexaploid (*T. aestivum*, $2n=42$) species that are traceable to an evolutionary diverge and clearly different ecological contexts. Aneuploidy, gain or loss of individual chromosomes that can drive dramatic phenotypic alteration, and the emergence of new species, has also been discovered by cytological studies. B chromosomes, supernumerary chromosomes not needed for life processes but could still affect certain characteristics, have been observed in many plant and animal taxa, allowing them to be used as extra cytological characters in taxonomy.

Since all members of a given species have the same number of chromosomes, karyotyping (the systematic determination of chromosomes in order of their size, shape, and other defined features) has also proven to be a vital tool for species identification. This strategy has proved especially informative in cryptic species complexes where unsuspected organisms of the same morphology differ in chromosome number and therefore correspond to different species. For example, the *Anopheles gambiae* complex, the major malaria vectors in Africa, includes several morphologically similar species that differ in their arrangement of chromosomes. Diversity in the number of chromosomes across related taxa has revealed insights into evolutionary trends and mechanisms. Fifteen years later, it became evident that dysploidy (i.e., the gradual increase or decrease of chromosome numbers by structural rearrangements rather than only by genome duplication) is a key evolutionary force for a number of plant families, including the Asteraceae and Poaceae. Changes to chromosome number can have important consequences for reproductive isolation, gene expression patterns and speciation events.



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4.3.1.3 Karyotype Analysis: Systematics and Evolutionary Insights

Karyotype analysis the systematic study of the complete set of chromosomes of a species has been widespread in cytotaxonomy and provided the basis for further insight into evolutionary pathways and process. Karyotyping would be a laborious but complete approach, as each species has a cytological profile determined based on chromosome number, chromosome size, position of the centromeres, and banding patterns that can be pinpointed exactly. Karyotype comparisons of related taxa may disclose perceived patterns of chromosomal evolution that reflect phylogenetic associations; however, questions as to the reliability of these methods in phylogenetic inference remain. Species that are closely related often have karyotypes that share some common features and are similar, while more distantly related groups tend to have karyotypes that are more divergent. But this relationship is not simple; rates of chromosomal evolution can differ greatly among lineages, with some groups retaining an extremely conserved karyotype for millions of years while other undergo rapid chromosomal reshuffling. The human karyotype has been precisely characterized, where humans have 46 chromosomes (or 23 pairs) and is usually used as a reference for comparative studies against other primates. Between humans and great apes, karyotype comparisons have shown several chromosomal rearrangements that took place during the course of primate evolution, notably the fusion of two ancestral chromosomes that generated human chromosome 2 an evidence of our evolutionary relationship with the remaining other primates that retain the paired chromosomes.

This has been especially useful in the study of polyploidy, hybridization, and speciation events. The wheat genus (*Triticum*) provides another illustrative example; karyotype analyses indicated that hexaploid bread wheat (*T. aestivum*) was contributed by three related ancestral genomes (termed A, B, and D). This information not only has elucidated evolutionary relationships within the grass family but also has been useful for breeding programs to enhance quality in crops. In animal taxonomy, karyotype analysis has proven particularly useful in clarifying species limits in those groups that are poorly differentiated morphologically. Cytotaxonomic studies have been of extreme importance in resolving cryptic species complexes among insects, amphibians, and mammals that can be segregated based on their specific karyotypes. For example, the water frog complex (*Pelophylax*) consists of several species and hybrid lineages that may be diagnosed reliably using karyotype data, and exhibit complex hybridization and polyploidization histories. Evolution of Karyotype Analysis: Spectral Karyotyping (SKY) and Multicolor FISH Advanced methods such as spectral karyotyping (SKY/7) and multicolor FISH have further



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improved the analysis of karyotype by visualizing all chromosomes at the same time with different color combinations. Such methods have uncovered previously inaccessible chromosomal features and rearrangements and have helped to further detail the evolution of karyotypes and their relationship with speciation.

Summary:

Cytology studies the structure, function, and behavior of cells, especially chromosomes, while taxonomy classifies and names organisms. Cytology contributes to taxonomy by providing chromosome numbers, structures, and behavior, which help determine relationships between plant groups. It detects phenomena like polyploidy, hybridization, and chromosomal mutations. Taxonomy integrates this cytological data with morphology, anatomy, embryology, and molecular evidence to classify plants more accurately. The combined field is called **cytotaxonomy**, which plays a crucial role in understanding plant evolution and resolving classification conflicts.

Multiple Choice Question(MCQs):

1. Cytology is primarily concerned with the study of:

- A) Ecosystems
- B) Cells
- C) Flowers
- D) Populations

Answer: B) Cells

2. Which of the following is **not** a contribution of cytology to taxonomy?

- A) Chromosome analysis
- B) Study of cell ultrastructure
- C) Soil nutrient analysis
- D) Karyotyping

Answer: C) Soil nutrient analysis

3. The combined study of cytology and taxonomy is called:

- A) Phytochemistry
- B) Cytotaxonomy
- C) Embryology



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D) Phylogeny

Answer: B) Cytotaxonomy

4. Who first used chromosome numbers as a tool in plant taxonomy?

A) Bentham

B) Hooker

C) Strasburger

D) Winge

Answer: D) Winge

5. Polyploidy detected through cytological studies helps in:

A) Identifying hybrids

B) Classifying lower plants

C) Determining soil pH

D) Estimating plant height

Answer: A) Identifying hybrids

Short Answer Questions

1. Define cytotaxonomy.
2. Mention two contributions of cytology to taxonomy.
3. What is the significance of chromosome number in taxonomy?
4. Give two examples of cytological techniques used in taxonomy.
5. How does cytology help in detecting hybrids?

Long Answer Questions

1. Discuss the major contributions of cytology to plant taxonomy.
2. Explain the role of cytology in understanding plant evolution.
3. Describe the importance of karyotype studies in taxonomy.
4. How does cytotaxonomy resolve taxonomic conflicts?

UNIT 4.4

Major contributions of Phytochemistry and Taxonomy



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4.4.1 Phytochemistry and Taximetrics – Introduction

Modern taxonomy relies on multiple lines of evidence to classify plants accurately. Two important approaches are **phytochemistry** and **taximetrics**.

- **Phytochemistry** is the study of naturally occurring chemical compounds in plants (like alkaloids, terpenoids, flavonoids, tannins, and essential oils) and their biosynthesis, distribution, and functions.
- **Taximetrics** (also called *numerical taxonomy*) is a method of classifying organisms based on **quantitative analysis of their characters**. It uses mathematical and statistical techniques to evaluate overall similarity between taxa.

4.4.1.1 Role of Phytochemistry in Taxonomy

Phytochemistry provides **chemical markers** that are often stable within a taxon and can be used to:

- Distinguish closely related species.
- Support or refute morphological classifications.
- Reveal evolutionary relationships (chemotaxonomy).

For example, glucosinolates are characteristic of **Brassicaceae**, alkaloids like morphine are typical in **Papaveraceae**, and volatile oils occur in **Rutaceae** and **Lamiaceae**. Such chemical traits add precision to plant identification and classification.

4.4.1.2 Taximetrics (Numerical Taxonomy)

Taximetrics applies **quantitative methods** to classify plants based on as many characters as possible, without giving preference to any one character.

Steps involved:

1. Select a wide range of morphological, anatomical, or chemical characters.
2. Score each taxon for these characters (presence/absence, measurements, etc.).



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3. Use statistical tools (like cluster analysis or similarity coefficients) to group taxa.

This method reduces subjectivity in traditional taxonomy and often reveals **natural clusters** or relationships that might not be evident through morphology alone.

Summary

Modern plant systematics often integrates chemical data into numerical analyses. By combining **phytochemical characters** with morphological traits in taximetric studies, botanists can obtain more reliable and reproducible classifications. This approach:

- Helps in resolving taxonomic controversies.
- Supports breeding programs by identifying chemically significant taxa.
- Assists in conservation by highlighting unique chemical lineages.

SELF ASSESSMENT QUESTIONS

Multiple Choice Questions (MCQs):

1. Who proposed the **Natural System of Classification** of angiosperms?
 - a) Linnaeus
 - b) Bentham and Hooker
 - c) Engler and Prantl
 - d) Takhtajan

Ans. b) Bentham and Hooker

2. The classification system of Bentham and Hooker was primarily based on:
 - a) Molecular phylogeny
 - b) Evolutionary relationships
 - c) Morphological characters
 - d) Genetic sequencing

Ans. c) Morphological characters

3. What is a major **merit** of the Bentham and Hooker system?
 - a) It classifies plants based on their evolutionary history
 - b) It is entirely artificial
 - c) It is easy to use and widely accepted in botanical studies
 - d) It does not use floral characters



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Ans. c) It is easy to use and widely accepted in botanical studies

4. A major **demerit** of the Bentham and Hooker system is that:
- a) It is entirely artificial
 - b) It places gymnosperms and angiosperms together
 - c) It does not consider evolutionary relationships
 - d) It ignores morphological characteristics

Ans. c) It does not consider evolutionary relationships

5. Engler and Prantl proposed the **Phylogenetic System** of classification based on:
- a) Evolutionary sequences
 - b) Flower color
 - c) Habitat preference
 - d) Seed structure

Ans. a) Evolutionary sequences

6. Which of the following is a **merit** of the Engler and Prantl classification?
- a) It was one of the first classifications based on phylogeny
 - b) It classified plants only based on floral structure
 - c) It ignored evolutionary history
 - d) It used only vegetative characteristics

Ans a) It was one of the first classifications based on phylogeny

7. What is **karyotype analysis** in taxonomy?
- a) Study of external plant features
 - b) Analysis of chromosome number and structure
 - c) Chemical profiling of plants
 - d) Classification of plants based on color

Ans b) Analysis of chromosome number and structure

8. Cytology contributes to plant taxonomy by:
- a) Studying floral arrangement
 - b) Identifying chromosome variations
 - c) Classifying plants based on leaf shape
 - d) Ignoring genetic makeup

Ans. b) Identifying chromosome variations

9. **Phytochemistry** is important in taxonomy because it helps:
- a) Identify plants based on genetic sequencing
 - b) Analyze the chemical composition of plants for classification



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- c) Study only the reproductive system of plants
- d) Identify only flowering plants

Ans. b) Analyze the chemical composition of plants for classification

10. Chemical profiling in phytochemistry is useful for:
- a) Studying cell division
 - b) Classifying plants based on their chemical compounds
 - c) Observing chromosome mutations
 - d) Determining plant height

Ans. b) Classifying plants based on their chemical compounds

Short Answer Questions:

1. What is the natural system of classification proposed by Bentham and Hooker?
2. List two merits and two demerits of the Bentham and Hooker system.
3. How does the Engler and Prantl system classify angiosperms?
4. What is the major difference between natural and phylogenetic classification?
5. How does cytology contribute to taxonomy?
6. Define karyotype analysis and its role in plant classification.
7. What is the significance of phytochemistry in taxonomy?
8. How does chemical profiling help in plant identification?
9. What is the role of medicinal plants in phytochemical studies?
10. Compare and contrast cytological and phytochemical approaches in taxonomy.

Long Answer Questions:

1. Explain the classification system of Bentham and Hooker, along with its merits and demerits.
2. Discuss the Engler and Prantl system of classification and compare it with Bentham and Hooker's system.
3. How does cytology contribute to plant taxonomy? Explain with examples.
4. Describe the role of chromosome structure and karyotype analysis in taxonomy.



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5. What are the contributions of phytochemistry in taxonomy and medicinal plant classification?
6. Discuss the importance of chemical profiling in identifying plant species.
7. Compare and contrast the cytological and phytochemical contributions to taxonomy.
8. How do chromosome number and structure influence plant classification?
9. What is the importance of the International Code of Botanical Nomenclature in classification?
10. Analyze the impact of molecular and chemical data on modern plant classification.

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MODULE -5

DIVERSITY OF FLOWERING PLANTS

5.0 Objectives

- Understand the general characteristics of dicot and monocot families.
- Identify key genera of major dicot and monocot plant families.
- Learn the economic importance of various flowering plant families.
- Recognize the diversity and significance of flowering plants in ecosystems and human life.

UNIT 5.1

General account of the Dicot families

5.1.1 Ranunculaceae (Buttercup Family)

General Introduction: The family **Ranunculaceae**, commonly known as the *Buttercup Family*, is a large and widely distributed family of dicotyledonous flowering plants. It comprises about 60 genera and over 2,500 species, occurring mainly in temperate and cold regions, with some representatives in subtropical areas. Members of this family are predominantly herbs, but some are climbers, shrubs, or even small woody plants.

Vegetative Characters: Most plants in Ranunculaceae are **herbaceous**, either annual or perennial, though a few are shrubs or woody climbers. The stems are often soft and sometimes hollow. Leaves are **alternate** or sometimes opposite, usually simple or compound, and often deeply lobed or dissected, giving them a feathery appearance. Stipules are generally absent. The foliage is often rich in alkaloids and other secondary metabolites, making some species poisonous if ingested.

Floral Characters: Flowers of Ranunculaceae are typically **actinomorphic** (radially symmetrical) and **bisexual**, though some species may have unisexual flowers. They are usually **complete** (having all floral whorls) and **hypogynous** (with superior ovary). The perianth is often petaloid; sepals and petals are usually free and variable in number, often five or more. Stamens are usually numerous and spirally arranged on the elongated receptacle, contributing to the family's characteristic showy appearance. Carpels are free



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(apocarpous) and numerous, arranged spirally on the receptacle, each carpel containing one to several ovules.

Inflorescence and Fruit: The inflorescence is typically a **raceme**, **cyme**, or solitary flower. Fruits are commonly **achenes** (dry, one-seeded, indehiscent) often produced in clusters, as seen in buttercups, or sometimes **follicles** (dehiscent fruits). Many species produce hooked or feathery styles that aid in seed dispersal by wind or animals.

Pollination and Floral Biology: Most members are **entomophilous** (insect-pollinated), attracting pollinators with their bright petals and abundant nectar, often secreted by modified petals or nectaries. The variation in floral structures among genera shows a range from simple to more complex forms, reflecting adaptations to diverse pollinators such as bees, flies, and beetles.

Economic Importance: Although the family is not a major source of food crops, it includes several **ornamental plants**, **medicinal species**, and some with toxic properties. For instance, **Ranunculus** (buttercups) are valued ornamentals but contain an acrid juice that can cause irritation. **Clematis** species are climbers commonly grown in gardens. **Aconitum** (aconite or monkshood) contains potent alkaloids used in traditional medicine and as a source of poison in history. **Delphinium** (larkspur) species are also grown as ornamentals. Despite some toxicity, certain species have been used in folk remedies, though caution is required.

Representative Genera: Important genera include **Ranunculus** (buttercups), **Clematis** (climbing ornamentals), **Aconitum** (medicinal but poisonous), **Delphinium** (ornamental larkspur), and **Anemone** (windflowers).



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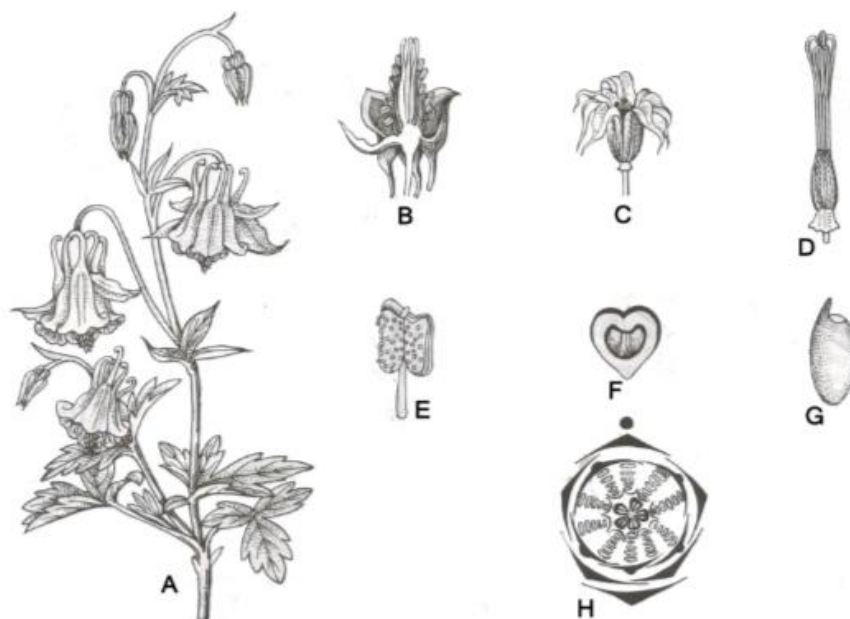


Fig: *Aquilegia vulgaris* (Ranunculaceae). (A) Part of plant bearing leaves and flowers (B) LS of flower, (C) Fruit composed of loose follicle, (D) Pistil, (E) Stamen (F) TS of an Ovary, (G) Seed, (H) Floral diagram.

Fig.5.1 *Aquilegia vulgaris*

5.1.2 Brassicaceae (Mustard Family)

General Introduction: The family **Brassicaceae**, also known as **Cruciferae** or the *Mustard Family*, is a large and economically important group of dicotyledonous plants. It comprises about **350 genera and over 3,500 species** distributed mainly in temperate and subtropical regions, though some extend to tropical mountains. Members of this family are well known for their characteristic cross-shaped (cruciform) flowers and their use as vegetables, oilseeds, condiments, and fodder.

Vegetative Characters: Most plants in Brassicaceae are **herbs** annual, biennial, or perennial though a few are shrubs. Stems are generally erect, often herbaceous, and sometimes succulent. Leaves are **simple**, **alternate**, and usually **exstipulate** (without stipules). They are often **lobed** or **pinnatifid** and may form a basal rosette in many species (e.g., radish and cabbage). The foliage often contains **mustard oils (glucosinolates)** which give them a characteristic pungent taste and smell.

Inflorescence: The most common type of inflorescence in this family is a **raceme**, often without bracts (ebracteate). Flowers are borne on short pedicels and open in succession from the base towards the top,



ensuring a long flowering period. This arrangement contributes to efficient cross-pollination.

Floral Characters: Flowers are **actinomorphic** (radially symmetrical), **bisexual**, and **complete**. They are typically **hypogynous** with a superior ovary. The floral formula is often summarized as:
 $\varnothing \oplus K_4 C_4 A_{2+4} G(2)$

- **Calyx:** 4 sepals in two whorls, free, usually green.
- **Corolla:** 4 free petals arranged in the form of a cross, giving the family its name *Cruciferae*.
- **Androecium:** 6 stamens arranged in two whorls; 4 long and 2 short (tetradynamous condition).
- **Gynoecium:** Bicarpellary, syncarpous, unilocular at first but becoming bilocular by a false septum (replum); ovary superior with many ovules on parietal placentation; style short with capitate stigma.

Fruit and Seeds: The fruit is typically a **silique** (long capsule, more than three times as long as broad) or **silicula** (shorter and broader capsule).

Pollination and Dispersal: Pollination is mainly **entomophilous**, carried out by bees, butterflies, and flies attracted to the bright petals and nectar.

Economic Importance: Brassicaceae is one of the most valuable plant families to humans. Many members are grown as **vegetables**, such as *Brassica oleracea* varieties (cabbage, cauliflower, broccoli, kohlrabi) and *Raphanus sativus* (radish). **Oil-yielding crops** include *Brassica napus* (rapeseed) and *Brassica juncea* (Indian mustard). Seeds of *Sinapis alba* (white mustard) and *Brassica nigra* (black mustard) are used as spices and condiments. Some species like *Arabis* and *Iberis* are grown as ornamentals. In addition, *Brassica* species are important in crop rotation and as fodder plants.

Representative Genera: **Brassica** – cabbage, cauliflower, mustard, broccoli., **Raphanus** – radish., **Sinapis** – mustard., **Arabis** – rockcress (ornamental)., **Iberis** – candytuft (ornamental).



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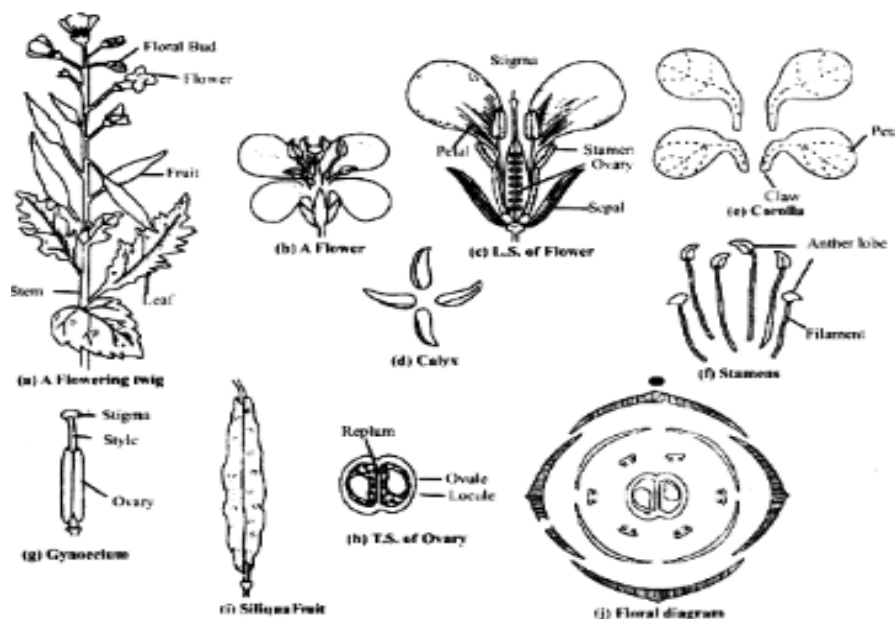


Fig. 5.2 Mustard

5.1.3 Malvaceae (Mallow Family)

General Introduction: The family **Malvaceae**, commonly known as the *Mallow Family*, is a large and economically significant family of dicotyledonous flowering plants. It comprises about **100 genera and 1,500 species** distributed widely in tropical and subtropical regions, with a few extending into temperate areas. Members of this family are known for their mucilaginous tissues, showy flowers, and fibrous stems. Many are important sources of food, fibre, timber, or ornamentals.

Vegetative Characters: Most plants in Malvaceae are **herbs, shrubs, or small to medium-sized trees**. The stems often contain mucilage and sometimes stellate (star-shaped) hairs. Leaves are **alternate**, simple or palmately lobed, and usually have **stipules**. The venation is typically reticulate, and the leaves often feel rough to the touch due to hairs. Many species have a characteristic slimy or mucilaginous sap when broken.

Inflorescence: The inflorescence is generally **axillary** or **terminal**, commonly forming **solitary flowers, fascicles, or racemes**. The flowers are often large, showy, and attract pollinators such as bees and butterflies.

Floral Characters: Flowers are **actinomorphic** (radially symmetrical), **bisexual**, and **complete**, with a typical floral formula:
 $\varnothing \oplus K(5) C5 A_{\infty} G(5)$



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- **Calyx:** Usually 5 sepals united at the base, often with an extra whorl called the **epicalyx** (a series of bracts resembling sepals).
- **Corolla:** 5 free petals, often twisted in the bud (twisted aestivation), brightly colored to attract insects.
- **Androecium:** Numerous stamens, typically united by their filaments into a **monadelphous staminal column** surrounding the style; anthers are often reniform (kidney-shaped).
- **Gynoecium:** Superior ovary, syncarpous, usually **penta- or multilocular**, with axile placentation and many ovules in each locule. Style often branches corresponding to the number of locules.

Fruit and Seeds: The fruit is usually a **schizocarp** that splits into several one-seeded **mericarps**, as in *Abelmoschus* (okra), or a **capsule** as in *Hibiscus*. Seeds are often kidney-shaped and rich in oil or mucilage, sometimes with hairs that aid in dispersal.

Pollination and Dispersal: Flowers are generally **entomophilous** (insect-pollinated), thanks to their bright petals and abundant nectar. The structure of stamens and stigmas promotes cross-pollination. Seed dispersal occurs through various means some by wind (due to hairs on seeds), others by water or animals.

Economic Importance

- **Gossypium** (cotton): The most important natural fibre crop worldwide.
- **Hibiscus rosa-sinensis** (China rose): A popular ornamental and used in traditional medicine.
- **Abelmoschus esculentus** (okra/ladies' finger): A widely grown vegetable.
- **Bombax ceiba** (silk-cotton tree): Provides floss used in cushions and as stuffing.
- **Durio** (durian): A tropical fruit tree in some classifications. The mucilage in many species also finds use in cosmetics, medicine, and food preparations.

Representative Genera: Some important genera include:

Hibiscus (ornamentals and fibre plants),

Gossypium (cotton species), **Abelmoschus** (okra),



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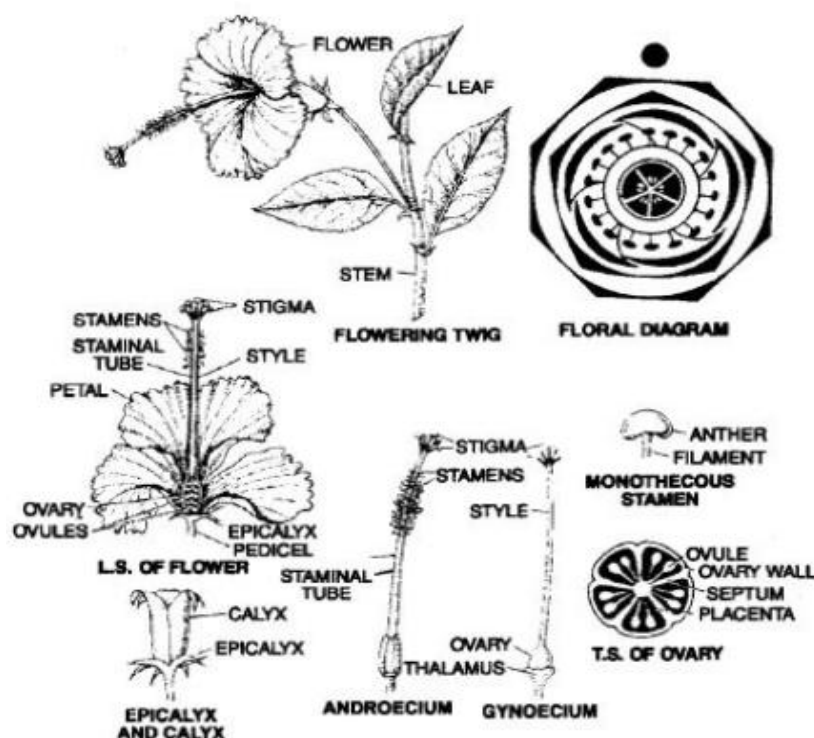


Fig. 5.3 Hibiscus

5.1.4 Rutaceae (Citrus Family)

General Introduction: The family **Rutaceae**, commonly known as the *Citrus Family*, is a medium-sized but economically important family of dicotyledonous flowering plants. It includes about **160 genera and over 2,000 species** that are widely distributed in tropical and subtropical regions, with a few in temperate areas. This family is best known for its **aromatic shrubs and trees**, many of which are cultivated for their edible fruits, essential oils, or timber.

Vegetative Characters: Members of Rutaceae are mostly **evergreen shrubs or small to medium trees**, though a few are herbs. The stems and leaves contain numerous **glandular oil cavities** filled with aromatic essential oils that give a characteristic smell when crushed. Leaves are **alternate** (rarely opposite), often **pinnate or trifoliate**, and generally **exstipulate**. The leaf margins are usually entire or slightly toothed, and translucent oil glands are often visible when held against the light.

Inflorescence: The inflorescence is variable but commonly **axillary cymes, panicles, or racemes**. In some species, flowers are **solitary** or in small clusters. Flowers are generally showy, fragrant, and attract a variety of pollinators.

Floral Characters: Flowers are **actinomorphic** (radially symmetrical), **bisexual**, and **complete**, typically **hypogynous** with a



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superior ovary. The general floral formula is:
 $\text{♀} \oplus K4-5 C4-5 A8-10 G(2-5)$

- **Calyx:** Usually 4 or 5 sepals, united at the base.
- **Corolla:** 4 or 5 free petals, white or colored, often thick and leathery.
- **Androecium:** Usually twice as many stamens as petals, arranged in two whorls; filaments often free or slightly united at the base.
- **Gynoecium:** Typically of 3–5 fused carpels (syncarpous), forming a **superior ovary** with axile placentation. Style is simple with a capitate stigma.
- **Nectaries:** A prominent disc is often present at the base of the ovary, secreting nectar to attract insects.

Fruit and Seeds: The fruit type varies within the family:

- In *Citrus* species (e.g., orange, lemon, lime), the fruit is a **hesperidium**—a special type of berry with a leathery rind rich in oil glands and juicy segments.
- In *Aegle marmelos* (bael), the fruit is a hard-shelled berry.
- In other genera, fruits may be **capsules**, **follicles**, or **schizocarps**.

Seeds are usually endospermic and often contain oil.

Pollination and Dispersal: Pollination is predominantly **entomophilous** (insect-pollinated), aided by the bright petals, fragrant oils, and nectar disc. Seeds are generally dispersed by animals (zoophily), either by consuming the fleshy fruits or by mechanical means.

Economic Importance: Rutaceae is one of the most important plant families for humans:

- **Edible Fruits:** *Citrus* species such as orange (*Citrus sinensis*), lemon (*C. limon*), lime (*C. aurantifolia*), grapefruit (*C. paradisi*), and mandarin (*C. reticulata*) are cultivated worldwide for their nutritious and vitamin-rich fruits.
- **Medicinal Plants:** *Aegle marmelos* (bael) is valued for its medicinal fruits and leaves. *Murraya koenigii* (curry leaf) is widely used in Indian cuisine and traditional medicine.
- **Timber and Ornamental Plants:** Some genera like *Ruta* and *Choisya* are used as ornamentals, and others provide timber or essential oils.



- Representative Genera:** Important genera include:

Aegle (bael), **Murraya** (curry leaf),



Introduction: The family **Fabaceae**, also known as **Leguminosae** or the *Legume Family*, is one of the largest and most economically important families of angiosperms. It comprises about **750 genera and nearly 19,000 species**, distributed all over the world, especially in tropical and subtropical regions, but also abundant in temperate zones. The family is characterized by its distinctive **legume (pod) fruit** and the ability of most species to form **root nodules housing nitrogen-fixing bacteria** (*Rhizobium*), which enriches soil fertility. Because of these features, Fabaceae holds a central position in agriculture, forestry, and horticulture.



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Vegetative Characters: Members of Fabaceae show great diversity in habit. Many are **herbs** (e.g., *Pisum*, *Cicer*), some are **shrubs** (*Sesbania*, *Indigofera*), while others are **climbers** (*Vigna*, *Lathyrus*) or **trees** (*Albizia*, *Dalbergia*). Stems are generally herbaceous but may be woody in shrubs and trees. In some genera, stems or leaves are modified into **tendrils** or **spines** for climbing and protection. Leaves are usually **alternate**, often **compound** either pinnate, bipinnate, or trifoliate and typically possess **stipules**, which may be large, small, or spine-like. A characteristic feature is the **pulvinus**, a swollen base of the leaf or leaflet that allows movements like sleep movements (nyctinasty).

Inflorescence and Flowers: The inflorescence in Fabaceae is commonly a **raceme**, **spike**, or **head** (capitulum). Flowers are generally **complete** (having all floral whorls), **bisexual**, and mostly **zygomorphic** (bilaterally symmetrical) in the subfamily Papilionoideae, though some groups like Mimosoideae have **actinomorphic** (radially symmetrical) flowers. The calyx usually consists of **five sepals** united at the base (gamosepalous), and the corolla is composed of **five petals**, arranged in a characteristic **papilionaceous** manner: one large upper petal (standard or vexillum), two lateral petals (wings), and two lower petals fused to form a boat-shaped keel. The androecium typically has **10 stamens**, often in a **diadelphous condition** (9 stamens united by their filaments into a sheath and 1 free) as seen in peas and beans, or sometimes **monadelphous** (all filaments united). The gynoecium is **monocarpellary**, with a **superior ovary**, unilocular, and bearing many ovules on **marginal placentation**. The style is usually slender, ending in a simple stigma.

Fruit and Seeds: The fruit is a **legume or pod**, a dry dehiscent fruit that splits open along both dorsal and ventral sutures. Examples include pea pods, bean pods, and tamarind pods. Seeds are usually **non-endospermic** (food stored in cotyledons) and are rich in proteins and carbohydrates, making them an essential part of human and animal diets. Many seeds also contain useful oils.

Pollination and Symbiosis: Pollination in Fabaceae is mainly **entomophilous** (insect-pollinated). The zygomorphic, papilionaceous flowers with their showy petals, nectar, and fragrance are specially adapted to bee pollination. Another remarkable feature of Fabaceae is the presence of **root nodules containing Rhizobium bacteria**, which fix atmospheric nitrogen into a form usable by plants. This symbiosis enriches the soil and makes Fabaceae crucial for sustainable agriculture and crop rotations.

Economic Importance



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- **Food and Pulses:** *Pisum sativum* (pea), *Cicer arietinum* (chickpea), *Lens culinaris* (lentil), *Phaseolus vulgaris* (bean), *Vigna radiata* (green gram), and *Arachis hypogaea* (groundnut) provide protein-rich seeds.
- **Fodder Plants:** *Medicago sativa* (alfalfa), *Trifolium* (clover) are widely used as livestock feed.
- **Timber and Dye:** *Dalbergia sissoo* (shisham) and *Pterocarpus santalinus* (red sandalwood) supply valuable wood and dyes.
- **Ornamental Plants:** *Cassia fistula* (golden shower), *Bauhinia variegata* (orchid tree) are planted for their attractive flowers.
- **Medicinal Plants:** *Abrus precatorius* (rosary pea) and *Senna* species are used in traditional medicine.
- **Soil Improvement:** Many are used as **green manure crops** (e.g., *Sesbania*), contributing to soil fertility through nitrogen fixation.

Representative Genera and Subfamilies

- **Papilionoideae (Faboideae):** Zygomorphic papilionaceous flowers (*Pisum*, *Cicer*, *Phaseolus*).
- **Caesalpinioideae:** Usually irregular flowers but not typically papilionaceous (*Cassia*, *Bauhinia*).

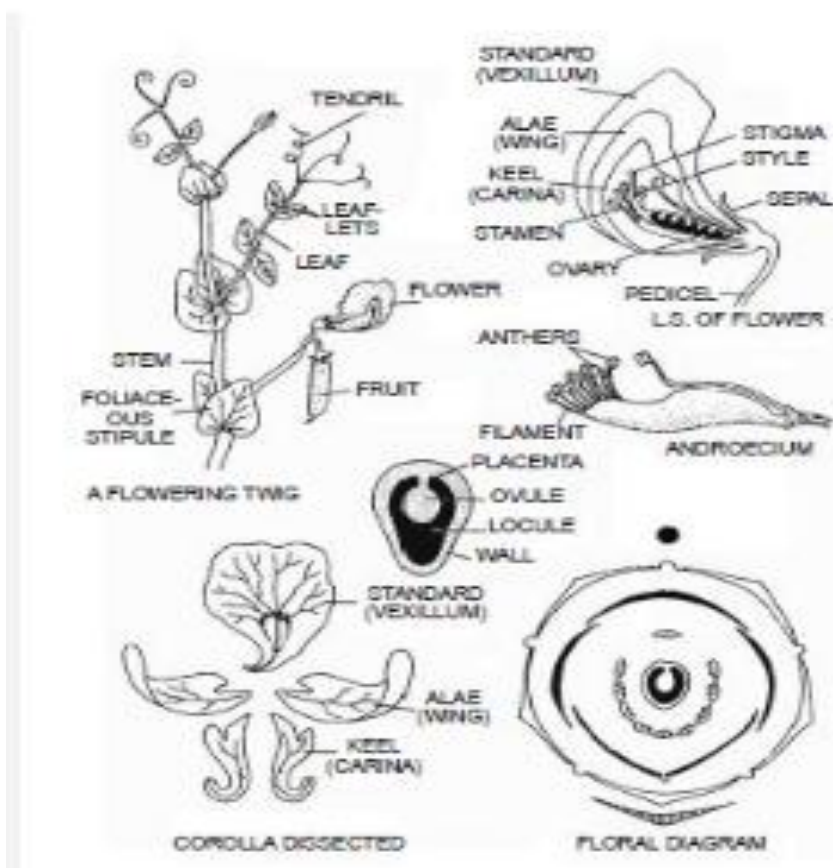


Fig. 5.5 Pea

5.1.5 Apiaceae (Carrot Family)

Introduction: The family **Apiaceae**, also known as **Umbelliferae** or the *Carrot Family*, is a large and distinctive family of flowering plants. It comprises about **300 genera and over 3,000 species** distributed widely in temperate and subtropical regions of the world, with many members growing in open fields and grasslands. Members of this family are easily recognized by their **hollow stems, aromatic foliage, and characteristic umbel inflorescence**. Many species are important as vegetables, spices, medicines, or ornamentals.

Vegetative Characters: Most members of Apiaceae are **herbs**, either annual or perennial, though some are subshrubs. Stems are generally **herbaceous, hollow, and furrowed**. Leaves are **alternate**, often **highly dissected or compound**, with sheathing leaf bases that clasp the stem. They are typically exstipulate (lacking stipules) but have a prominent **petiole base forming a sheath**. Many species contain **aromatic oil ducts (vittae)** in their leaves and stems, giving them characteristic scents (like in carrot, coriander, fennel).



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Inflorescence and Flowers: The inflorescence is a **compound umbel**, which is a hallmark of this family. A compound umbel consists of several smaller umbels (umbellets) radiating from the tip of the peduncle, often subtended by an involucre of bracts. Flowers are usually **small, actinomorphic (radially symmetrical), bisexual, and epigynous** (inferior ovary).

- **Calyx:** Generally 5 small sepals, often reduced or inconspicuous.
- **Corolla:** 5 free petals, usually white, yellow, or sometimes purple, often notched or inflexed at the tip.
- **Androecium:** 5 stamens alternating with petals.
- **Gynoecium:** Bicarpellary, syncarpous, with an **inferior ovary**, two locules, and a stylopodium (swollen nectariferous disc at the style base).

Floral formula: $\text{♀} \oplus K5 C5 A5 G(2)$ (inferior)

Fruit and Seeds: The fruit is a **schizocarp** that splits into two **mericarps** when mature. Each mericarp contains a seed and has longitudinal ridges with oil ducts (vittae) between them. The seeds are typically small and aromatic, used as spices (like coriander seeds or fennel seeds).

Pollination and Dispersal: Pollination is mostly **entomophilous** (insect-pollinated), as the flowers produce nectar on the stylopodium. The small size of individual flowers is compensated by their arrangement in large, showy umbels that attract a wide range of insects. Fruits are dispersed by wind, water, or animals, aided by their small size and sometimes wing-like ribs.

Economic Importance

- **Vegetables:** *Daucus carota* (carrot), *Apium graveolens* (celery), *Pastinaca sativa* (parsnip).
- **Spices and Condiments:** *Coriandrum sativum* (coriander/dhania), *Foeniculum vulgare* (fennel/saunf), *Cuminum cyminum* (cumin/jeera), *Anethum graveolens* (dill).
- **Medicinal Plants:** *Centella asiatica* (Brahmi), *Heracleum* species (used in traditional remedies), *Angelica archangelica* (used in herbal medicine).
- **Aromatic Oils:** Many genera yield essential oils used in perfumery and flavoring.

Representative Genera: Important genera include **Daucus** (carrot), **Coriandrum** (coriander), **Foeniculum** (fennel), **Cuminum** (cumin),

Apium (celery), **Centella** (medicinal herb), and **Heracleum** (hogweed).

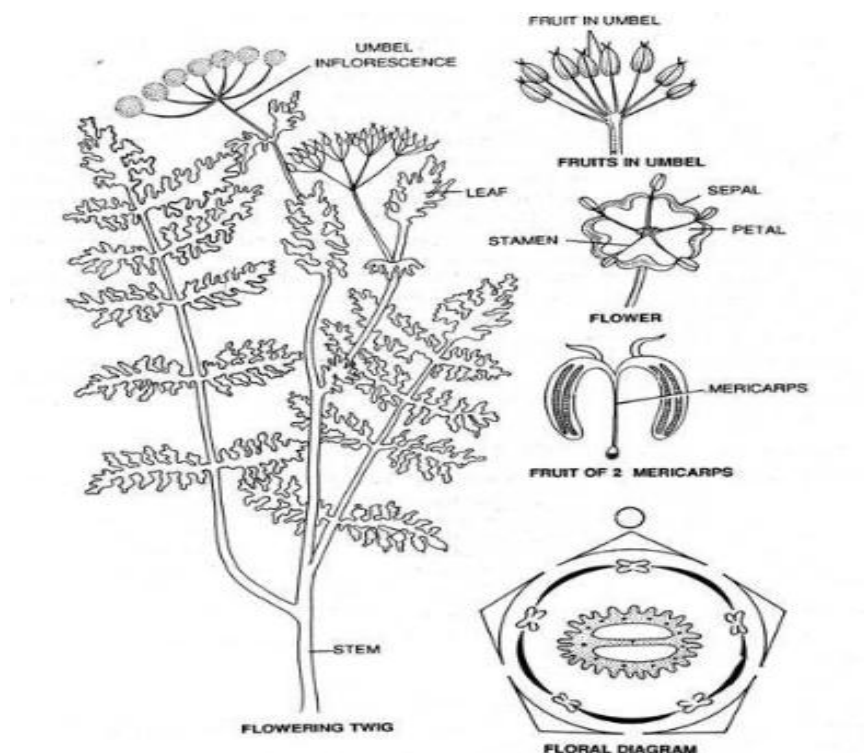


Fig.5.6 Daucus (carrot)

5.1.6 Acanthaceae (Acanthus Family)

Introduction: The family **Acanthaceae**, commonly called the *Acanthus Family*, is a large and diverse group of flowering plants. It includes about **250 genera and over 3,500 species** distributed widely in tropical and subtropical regions, with a few in temperate areas. Members are mostly **herbs, shrubs, and climbers**, many of which are cultivated for their ornamental value due to their brightly colored and uniquely shaped flowers. Several species also have medicinal uses, and a few are weeds in cultivated fields.

Vegetative Characters: Most Acanthaceae are **herbaceous perennials or shrubs**, though some are small trees or twining climbers. The stems are often quadrangular in cross-section. Leaves are **simple, opposite**, usually **exstipulate** (without stipules), and often have entire or toothed margins. The leaves are generally rich green and may be hairy or glabrous. Some genera have spiny bracts or bracteoles associated with the flowers.

Inflorescence and Flowers: The inflorescence is commonly a **spike, raceme, or head**, often terminal or axillary, and subtended by large, sometimes spiny **bracts and bracteoles** that give a distinctive



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appearance. Flowers are typically **zygomorphic** (bilaterally symmetrical), **bisexual**, and **complete**, often large and showy.

- **Calyx:** Usually 4 or 5 sepals, free or slightly united, often unequal.
- **Corolla:** 5 petals united into a **bilabiate (two-lipped) tubular corolla**, often brightly colored (red, orange, purple, or yellow).
- **Androecium:** Usually 4 stamens in didynamous condition (two long and two short), sometimes only 2 are fertile; filaments are epipetalous (arising from the corolla tube).
- **Gynoecium:** Bicarpellary, syncarpous, superior ovary with two locules and axile placentation; stigma is simple or bilobed.

Floral Formula: $\text{♀} \uparrow K(5) C(5) A4 G(2)$

Fruit and Seeds: The fruit is generally a **loculicidal capsule**, often explosively dehiscent, throwing out seeds forcefully when mature. Seeds are typically flattened, often with hygroscopic hairs or sticky surfaces that aid in attachment to soil or dispersal agents.

Pollination and Dispersal: Flowers are commonly **entomophilous** (pollinated by insects), particularly bees, butterflies, and sometimes birds, attracted by their bright colors and nectar. The explosive dehiscence of capsules helps in effective seed dispersal, spreading seeds some distance from the parent plant.

Economic Importance

- **Ornamental Plants:** *Ruellia*, *Thunbergia* (clock vine, blue trumpet vine), *Barleria*, and *Crossandra* are widely cultivated for their attractive flowers.
- **Medicinal Uses:** *Adhatoda vasica* (Vasaka) is a well-known medicinal plant whose leaves are used to treat respiratory ailments due to alkaloids like vasicine. *Justicia adhatoda* is also valued in Ayurvedic medicine.
- **Hedges and Ground Covers:** Many shrubby members are planted as live fences or ground covers in gardens.

Representative Genera: Important genera include **Adhatoda** (medicinal), **Thunbergia** (ornamental climbers), **Barleria** (hedge plants), **Ruellia** (ornamentals), **Justicia** (medicinal and ornamental), and **Crossandra** (garden plants with bright flowers).

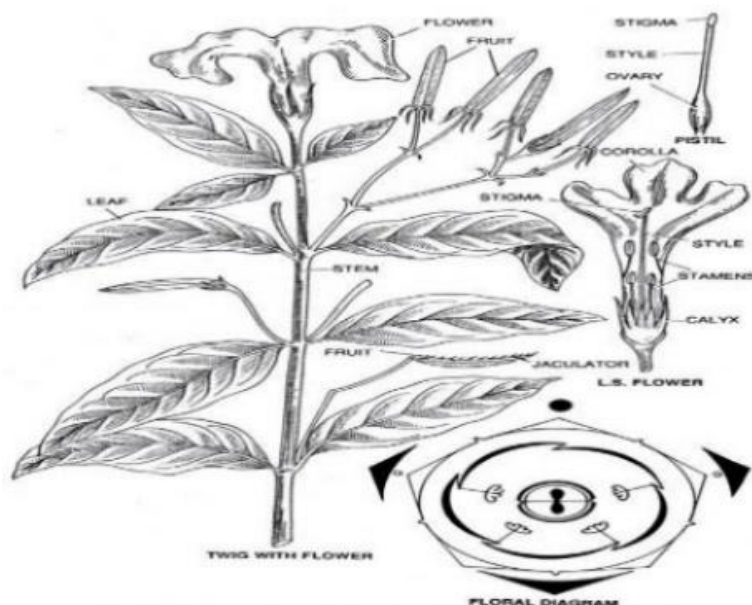


Fig. 27.1. Acanthaceae, *Ruellia prostrata* Lamk.; Verna, Kalighawani.

Fig. 5.7 *Adhatoda*

5.1.7 Apocynaceae (Dogbane Family)

Introduction: The family **Apocynaceae**, commonly called the *Dogbane Family*, is a large family of flowering plants that includes many tropical and subtropical species. It consists of about **400 genera and over 5,000 species** distributed worldwide, with a high diversity in tropical regions. Members are mainly **trees, shrubs, climbers, or lianas**, often with **milky latex**. Many are known for their ornamental flowers, some for their medicinal uses, and a few for their poisonous properties due to alkaloids and glycosides present in their tissues.

Vegetative Characters: Most members are **evergreen shrubs or trees**, though some are **woody climbers or twining herbs**. Stems often contain abundant **white latex**, a characteristic feature of the family. Leaves are usually **simple, entire, exstipulate**, and arranged **opposite or whorled**, though rarely alternate. They are typically leathery or coriaceous and often shiny. In some species, the leaves are reduced or modified, but they commonly show a clear midrib with reticulate venation.

Inflorescence and Flowers: The inflorescence is commonly **terminal or axillary cymes, panicles**, or sometimes **solitary**. Flowers are usually **complete, bisexual, actinomorphic** (radially symmetrical), and **hypogynous** with a **superior ovary**. They are often large, showy, and sweet-scented.

- **Calyx:** Usually 5 sepals, free or united at the base.



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- **Corolla:** Typically 5 petals, united into a **salver-shaped or funnel-shaped corolla**, often twisted in bud (contorted aestivation).
- **Androecium:** 5 stamens, epipetalous (inserted on the corolla tube), often with anthers closely appressed around the stigma.
- **Gynoecium:** Bicarpellary, syncarpous, with two carpels usually free at the base but united at the stigma; placentation is **axile** with many ovules in each carpel.

Floral formula: $\text{♀} \oplus K(5) C(5) A5 G(2)$

Fruit and Seeds: The fruit is often a **pair of follicles** (each developing from one carpel) that may be free or united at the tips. In some species, the fruit may be a **berry** or a **capsule**. Seeds are usually numerous, often with **tufts of silky hairs (coma)** to aid in wind dispersal, as seen in *Calotropis* and *Nerium*. Some seeds are winged or adapted for other means of dispersal.

Pollination and Dispersal: Flowers are mostly **entomophilous** (insect-pollinated), attracting pollinators with their bright petals, fragrance, and nectar. The specialized floral structures of some genera (like pollinia in milkweeds) enhance cross-pollination. Seeds are commonly dispersed by wind due to their comose hairs.

Economic Importance

Ornamentals: *Nerium oleander* (oleander), *Plumeria* (frangipani), *Catharanthus roseus* (periwinkle) are widely grown for their beautiful flowers.

Medicinal Plants: *Catharanthus roseus* is a source of alkaloids (vincristine, vinblastine) used in cancer treatment; *Rauvolfia serpentina* provides reserpine for treating hypertension; *Holarrhena antidysenterica* is used in traditional medicine.

Timber and Fiber: Some trees are used for timber, while *Calotropis* yields a silky fiber from its seeds.

Toxic Plants: Many species contain cardiac glycosides or alkaloids and are poisonous if ingested, hence used carefully in medicine.

Representative Genera: Important genera include **Nerium** (oleander), **Plumeria** (temple tree or frangipani), **Catharanthus** (periwinkle), **Rauvolfia** (serpentine), **Holarrhena** (kurchi), **Calotropis** (milkweed), and **Tabernaemontana** (crepe jasmine).

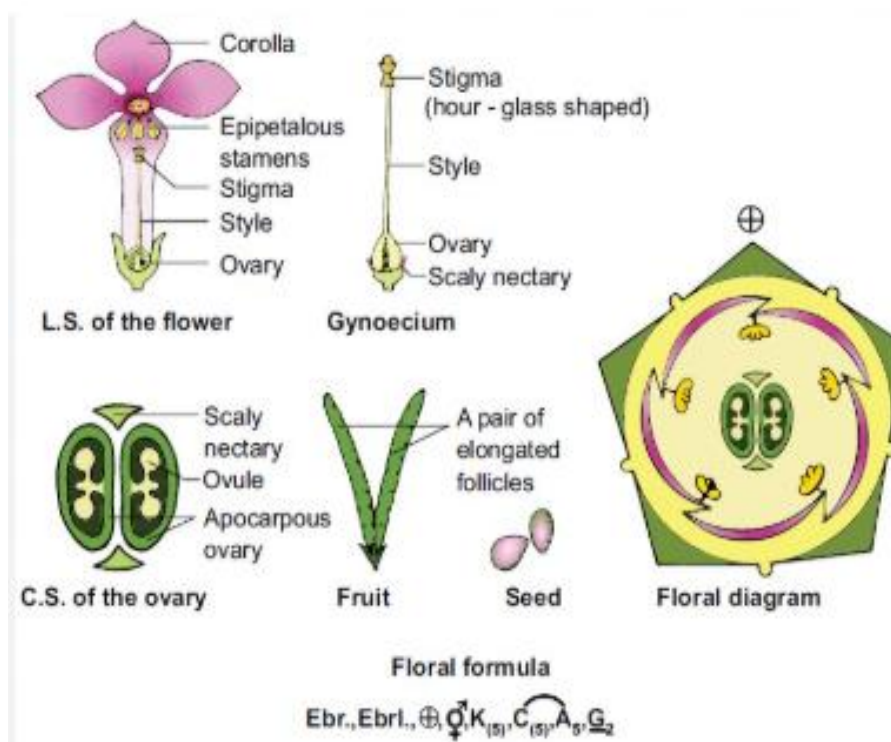


Fig. 5.8 Catharanthus (periwinkle),

5.1.8 Solanaceae (Nightshade Family)

Introduction: The family **Solanaceae**, commonly called the *Nightshade Family*, is a large and economically important family of flowering plants. It consists of about **90 genera and over 2,700 species**, found mostly in tropical and subtropical regions, with some species in temperate zones. Many members are cultivated worldwide for food, spices, ornamentals, and medicines. This family is noted for its diversity, ranging from herbs and shrubs to small trees and climbers, and for producing a variety of useful alkaloids.

Vegetative Characters: Members of Solanaceae are usually **herbs**, but some are **shrubs, small trees, or climbers**. Stems are typically herbaceous, sometimes woody at the base, and may be angular or covered with glandular hairs. Leaves are **simple**, rarely pinnately compound, **alternate**, exstipulate (without stipules), and often show variations in size and shape on the same plant (heterophylly). The foliage of many species contains alkaloids, making them toxic or medicinal.

Inflorescence and Flowers: The inflorescence is typically **axillary cymes, racemose clusters**, or sometimes **solitary axillary flowers**. Flowers are generally **complete, bisexual**, and **actinomorphic** (radially symmetrical).



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- **Calyx:** Usually 5 sepals, united (gamosepalous), forming a persistent calyx.
- **Corolla:** 5 petals, united (gamopetalous), often rotate, funnel-shaped, or tubular, with valvate or twisted aestivation.
- **Androecium:** 5 stamens, epipetalous (inserted on the corolla tube), alternating with petals.
- **Gynoecium:** Bicarpellary, syncarpous, **superior ovary**, bilocular with axile placentation, style simple, stigma capitate.

Floral Formula: $\text{♀} \oplus K(5) C(5) A5 G(2)$

Fruit and Seeds: The fruit is usually a **berry** (e.g., tomato, brinjal) or a **capsule** (e.g., Datura, Petunia). Seeds are typically numerous, endospermic, and often flattened or kidney-shaped. Many fruits are edible, while others are toxic due to alkaloids.

Pollination and Dispersal: Pollination is mainly **entomophilous** (insect-pollinated) owing to bright corollas and nectar production. The fruits, especially berries, are dispersed by **birds and animals** that eat them and scatter seeds. Capsules often release seeds by mechanical dehiscence.

Economic Importance

Vegetables: *Solanum melongena* (brinjal/eggplant), *Solanum tuberosum* (potato), *Capsicum annuum* (chilli, capsicum), *Lycopersicon esculentum* (tomato).

Medicinal Plants: *Atropa belladonna* (belladonna, source of atropine), *Datura stramonium* (source of scopolamine and hyoscine), *Hyoscyamus niger* (henbane).

Ornamentals: *Petunia hybrida* (garden petunia), *Cestrum nocturnum* (night-blooming jasmine).

Industrial Plants: *Nicotiana tabacum* (tobacco) for nicotine and cigarettes.

Representative Genera: Important genera include **Solanum** (potato, brinjal), **Capsicum** (chillies, paprika), **Lycopersicon** (tomato), **Nicotiana** (tobacco), **Datura** (thorn apple), **Atropa** (belladonna), **Petunia** (ornamental), and **Cestrum**

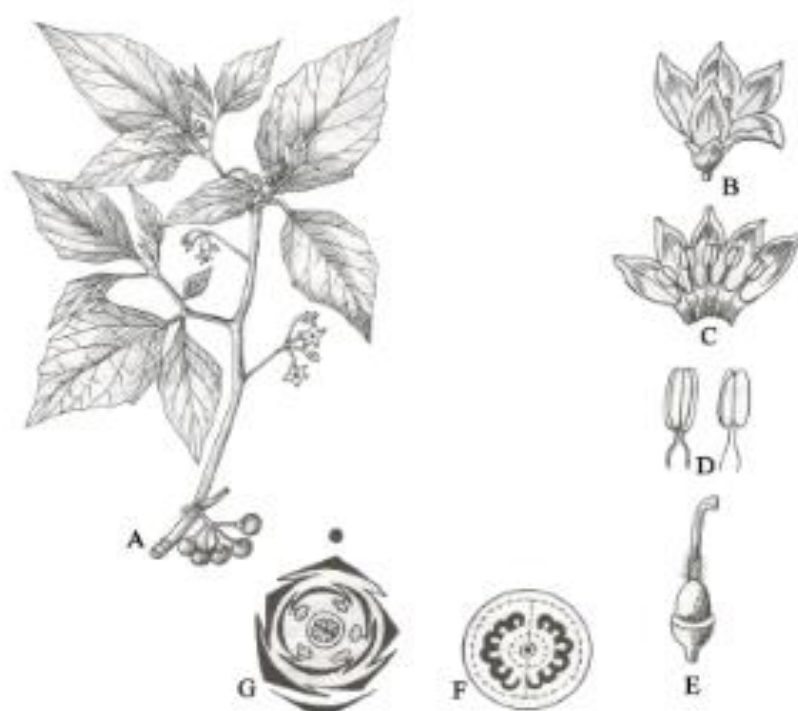


Fig:- *Solanum nigrum*. (A) Portion of flowering twig, (B) Flower, (C) Corolla, (D) Androecium, (E) Gynoecium, (F) TS of ovary, (G) Floral diagram.

Fig.5.9 Solanum

5.1.9 Lamiaceae (Mint Family)

Introduction: The family **Lamiaceae**, commonly known as the *Mint Family* or *Labiatae*, is a large and economically important family of flowering plants. It includes about **250 genera and over 7,000 species** distributed worldwide, especially in the Mediterranean region and other warm temperate areas. Plants of this family are well known for their **aromatic foliage** due to the presence of essential oils, as well as for their characteristic **bilabiate (two-lipped) flowers**. Many members are culinary herbs, medicinal plants, and ornamentals.

Vegetative Characters: Most members of Lamiaceae are **aromatic herbs or shrubs**, though a few are small trees or climbers. The stems are typically **quadrangular (square in cross-section)**, which is a diagnostic feature of the family. Leaves are **simple, opposite and decussate** (each pair at right angles to the next), usually **exstipulate** (without stipules), and often have glandular trichomes that secrete fragrant essential oils. The leaves may be entire or toothed, and sometimes densely hairy.

Inflorescence and Flowers: The inflorescence is typically a **verticillaster** (a false whorl formed by condensed dichasial cymes),



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often appearing like a whorl at each node. Flowers are **zygomorphic** (bilateral symmetry), **bisexual**, and **complete**.

- **Calyx:** Usually 5 sepals, united (gamosepalous), often tubular and persistent, sometimes two-lipped.
- **Corolla:** 5 petals, united (gamopetalous), forming a **bilabiate corolla**—the upper lip formed by two petals and the lower lip by three petals.
- **Androecium:** Usually 4 stamens (didynamous—two long and two short), inserted on the corolla tube (epipetalous); sometimes only 2 are fertile.
- **Gynoecium:** Bicarpellary, syncarpous, **superior ovary**, deeply 4-lobed with a gynobasic style (style arising from the center of the lobes), and axile placentation.

Floral Formula: $\text{♀} \uparrow K(5) C(5) A_4 G(2)$

Fruit and Seeds: The fruit is typically a **schizocarp**, which splits into four one-seeded **nutlets**. Seeds are generally endospermic and often oily, aiding germination and sometimes dispersal.

Pollination and Dispersal: Flowers are mostly **entomophilous** (insect-pollinated), adapted for bee and butterfly visits through their bilabiate corolla and nectar guides. The aromatic oils also attract pollinators. The small nutlets are dispersed by gravity, ants, or other small animals.

Economic Importance: The Lamiaceae family is especially valued for its aromatic herbs and medicinal plants:

Culinary Herbs and Spices: *Ocimum sanctum* (holy basil), *Ocimum basilicum* (sweet basil), *Mentha spicata* (spearmint), *Mentha piperita* (peppermint), *Salvia officinalis* (sage), *Rosmarinus officinalis* (rosemary), *Thymus vulgaris* (thyme), *Origanum vulgare* (oregano).

Medicinal Plants: *Ocimum sanctum* (tulsi) in traditional medicine, *Salvia* (sage) with antiseptic and healing properties.

Ornamentals: *Coleus* species (foliage plants), *Leonotis* (lion's ear).

Industrial Uses: Essential oils from *Mentha* species are used in toothpaste, cosmetics, and flavoring industries.

Representative Genera: Important genera include **Ocimum** (basil, tulsi), **Mentha** (mints), **Salvia** (sage), **Thymus** (thyme), **Rosmarinus** (rosemary), **Coleus** (ornamental), and **Leonurus** (medicinal herbs).

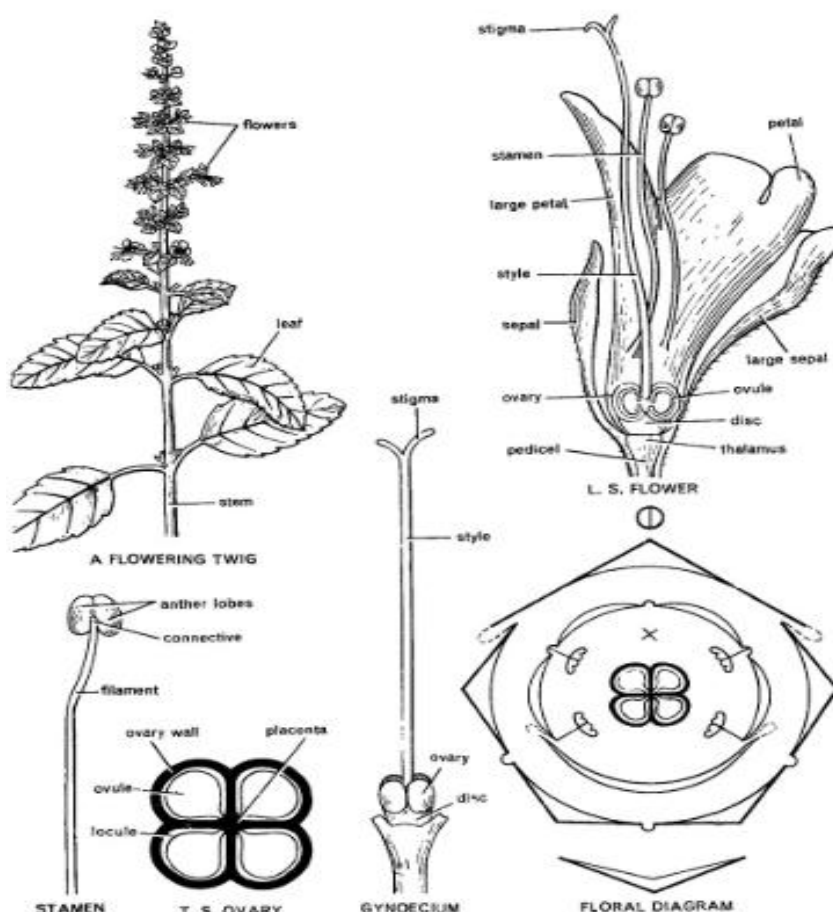


Fig. 5.10 *Ocimum* (basil, tulsi),

5.1.10 Chenopodiaceae (Goosefoot Family)

Introduction: The family **Chenopodiaceae**, commonly known as the *Goosefoot Family*, is a group of mostly herbaceous flowering plants adapted to dry, saline, or alkaline habitats. It includes about **100 genera and 1,700 species** distributed worldwide, especially in temperate and subtropical regions. Many members are halophytes (salt-tolerant plants) growing in seashores, salt marshes, or dry wastelands. Some species are important as food crops, leafy vegetables, or sources of fodder and salt accumulation, while others are weeds.

Vegetative Characters: Most members are **annual or perennial herbs**, sometimes subshrubs, with succulent or woody stems. The stems are often striated or angular, and many species show xerophytic adaptations such as reduced leaves. Leaves are **simple, alternate** (sometimes opposite), generally **exstipulate** (without stipules), and often succulent or mealy due to bladder hairs that store water and salts. Margins are entire or lobed, and venation is reticulate but often obscure in fleshy leaves. Many species thrive in saline soils and have special salt-secreting tissues.



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Inflorescence and Flowers: The inflorescence is typically a **spike, panicle, or head**, often small and inconspicuous. Flowers are **actinomorphic** (radially symmetrical), **bisexual** (rarely unisexual), **hypogynous**, and generally lacking showy petals.

- **Perianth:** Usually 5 green tepals (sepaloid), free or united at the base.
- **Androecium:** Stamens 1–5 (often equal in number to the tepals and opposite them), with versatile anthers.
- **Gynoecium:** Bicarpellary, syncarpous, superior ovary, unilocular with basal or parietal placentation; stigma often bifid or capitate. Because the flowers are often small and greenish, they rely on wind or self-pollination rather than animal pollinators.

Floral Formula: $\text{♀} \oplus \text{P}(5) \text{A}_5 \text{G}(2)$

Fruit and Seeds: The fruit is typically an **achene** (one-seeded indehiscent fruit) or a thin-walled utricle enclosed by the persistent perianth. Seeds are often small, with abundant perisperm or endosperm, and may have a curved or spiral embryo.

Pollination and Dispersal: Pollination is mostly **anemophilous** (wind-pollinated), reflected in the inconspicuous, non-petaloid flowers. Dispersal is by wind or sometimes water, as many species grow near coasts or wetlands. Some seeds are buoyant, while others are dispersed by animals through ingestion or adhesion.

Economic Importance Food Crops: *Spinacia oleracea* (spinach), *Beta vulgaris* (beetroot, sugar beet), *Chenopodium quinoa* (quinoa), *Chenopodium album* (bathua, eaten as a leafy vegetable).

Fodder Plants: *Atriplex* (saltbush) used as forage in arid regions.

Industrial Uses: Sugar is extracted from *Beta vulgaris* (sugar beet). Some species are used to obtain soda ash and potash from their ash.

Weeds: Certain *Chenopodium* species are common weeds in agricultural fields.

Representative Genera: Important genera include **Chenopodium** (goosefoot, quinoa, bathua), **Beta** (beets), **Spinacia** (spinach), **Atriplex** (saltbush), and **Salicornia** (glasswort).

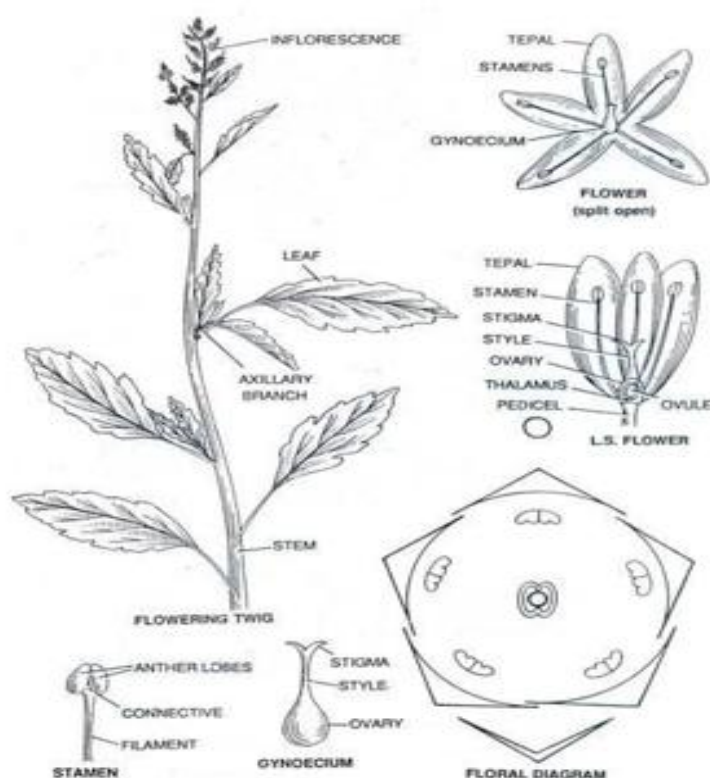


Fig. 5.11 *Chenopodium* (goosefoot)

5.1.11 Euphorbiaceae (Spurge Family)

Introduction: The family **Euphorbiaceae**, commonly known as the *Spurge Family*, is a large and diverse family of flowering plants. It comprises about **300 genera and over 7,500 species**, widely distributed in tropical and subtropical regions, with some members in temperate zones. Members include herbs, shrubs, climbers, and trees. A striking feature of many species is the presence of **milky latex**, which often contains toxic or medicinal compounds. This family shows remarkable variation in floral structure, ranging from normal flowers to highly specialized unisexual flowers in unique inflorescences called **cyathia**.

Vegetative Characters: Members of Euphorbiaceae range from small **herbs** (like *Euphorbia hirta*), to **shrubs** and **trees** (like *Ricinus communis* – castor oil plant), and even some **succulent or cactus-like forms** (like *Euphorbia trigona*). The stems often exude a characteristic **white latex** when cut, which may be poisonous or irritant. Leaves are generally **simple, alternate**, often **exstipulate** (without stipules), but stipules may be present and sometimes modified into spines (e.g., *Euphorbia splendens*). In some xerophytic members, leaves are reduced or ephemeral, and photosynthesis is carried out by the green stems.



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Inflorescence and Flowers: The inflorescence varies widely in this family, but many species, particularly *Euphorbia*, bear a highly specialized **cyathium**—a cup-like involucre formed by fused bracts enclosing several reduced unisexual flowers (a single pistillate flower in the center surrounded by numerous staminate flowers), giving the appearance of a single flower. Other genera may bear racemes, spikes, or solitary flowers. Flowers are **unisexual** (plants may be monoecious or dioecious), **actinomorphic**, and usually **incomplete**:

- **Perianth:** Usually simple; some flowers lack petals entirely, while others have petaloid sepals.
- **Male Flowers:** Stamens are often numerous, free or united in groups.
- **Female Flowers:** Gynoecium tricarpellary, syncarpous, ovary superior, trilocular with axile placentation; styles are often branched.

Floral Formula: For a typical *Euphorbia* flower:
 Male flower: ♂ $\oplus$ P0 A1 G0
 Female flower: ♀ $\oplus$ P0 A0 G(3)

Fruit and Seeds: The fruit is typically a **schizocarpic capsule**, often called a **regma**, which splits into three one-seeded cocci when mature. Seeds are often provided with a fleshy appendage called a **caruncle** that attracts ants, aiding in **myrmecochory** (seed dispersal by ants). Seeds are generally rich in oils, some edible and some toxic.

Pollination and Dispersal: Pollination in Euphorbiaceae is mostly **entomophilous**, especially in species with bright-colored bracts (like *Euphorbia pulcherrima*, the poinsettia). In others with inconspicuous flowers, wind pollination can also occur. Seeds are dispersed by explosive dehiscence of the capsule or by ants attracted to the caruncle.

Economic Importance: The Euphorbiaceae family is of great economic significance:

Oils and Fats: *Ricinus communis* (castor oil plant) for castor oil; *Manihot esculenta* (cassava/tapioca) for starch and edible tubers.

Medicinal Plants: *Euphorbia hirta* (asthma herb), *Croton tiglium* (source of croton oil used as purgative).

Ornamentals: *Euphorbia pulcherrima* (poinsettia), *Euphorbia milii* (crown of thorns).

Timber and Rubber: *Hevea brasiliensis* (para rubber tree) is the chief source of natural rubber.

Toxic Plants: Many species contain irritating latex or alkaloids, such as *Hura crepitans* (sandbox tree).

Representative Genera: Important genera include **Euphorbia** (spurge, poinsettia), **Ricinus** (castor oil plant), **Hevea** (rubber tree), **Manihot** (cassava), **Croton**, **Phyllanthus** (used in Ayurveda), and **Acalypha** (ornamentals and medicines).

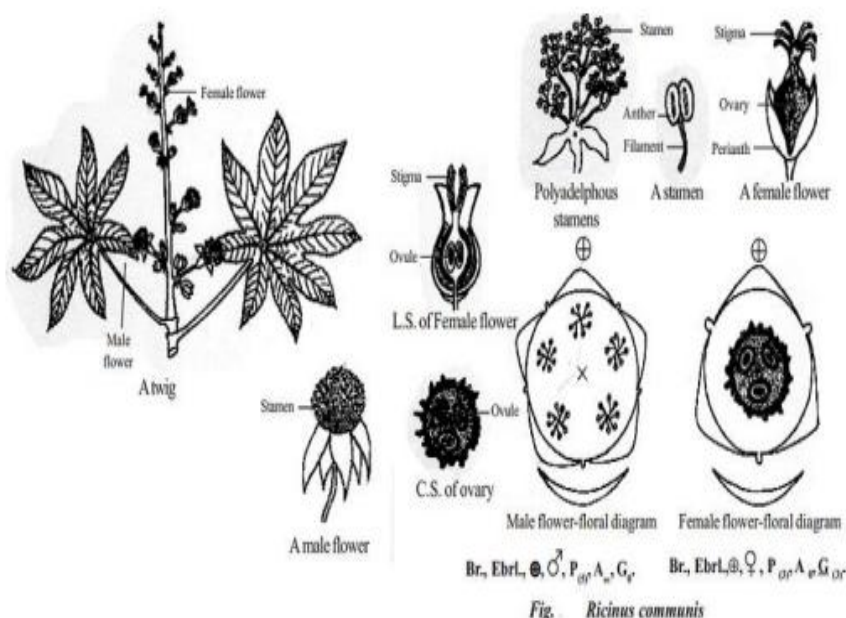


Fig: Euphorbiaceae *Ricinus communis*

Fig. 5.12 Euphorbia

Summary:

Dicotyledons are angiosperms with **two cotyledons** in the seed. They typically have a **tap root system**, **reticulate venation**, and **secondary growth** due to **open vascular bundles arranged in a ring**. Leaves are usually dorsiventral with **stipules**, and flowers are mostly **pentamerous**, either **actinomorphic** or **zygomorphic**. The androecium may be free or fused, and the gynoecium is usually syncarpous with a superior ovary. Fruits are variable, including **legume, capsule, drupe, berry, or schizocarp**.



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Major dicot families like **Fabaceae, Solanaceae, Malvaceae, Brassicaceae, Asteraceae, Lamiaceae, Euphorbiaceae, and Rosaceae** are distinguished by combinations of vegetative and floral features. Dicots are economically important for food, fiber, medicine, ornamentals, and timber.

Multiple Choice Question (MCQs):

1. Dicot seeds are characterized by:

- A) One cotyledon
- B) Two cotyledons
- C) Three cotyledons
- D) No cotyledons

Answer: B) Two cotyledons

2. Which type of venation is typical of dicots?

- A) Parallel
- B) Reticulate
- C) Oblique
- D) Pinnate

Answer: B) Reticulate

3. The vascular bundles in dicot stems are:

- A) Scattered and closed
- B) Scattered and open
- C) Arranged in a ring and open
- D) Arranged in a ring and closed

Answer: C) Arranged in a ring and open

4. The floral symmetry of most dicots is:

- A) Zygomorphic only
- B) Actinomorphic only
- C) Actinomorphic or zygomorphic
- D) None of these

Answer: C) Actinomorphic or zygomorphic



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5. Which of the following is a major dicot family?

- A) Poaceae
- B) Fabaceae
- C) Cyperaceae
- D) Orchidaceae

Answer: B) Fabaceae

Short Answer Questions

1. Define dicotyledons and mention two distinguishing vegetative features.
2. Describe the root system and leaf venation in dicots.
3. Write the general floral characteristics of dicots.
4. Name four economically important dicot families.
5. Mention two diagnostic characters that distinguish dicots from monocots.

Long Answer Questions

1. Write a general account of dicotyledons, including vegetative and reproductive characters.
2. Describe the characteristic features of three important dicot families: Fabaceae, Solanaceae, and Malvaceae.
3. Discuss the economic importance of dicot families with examples.
4. Explain how dicot families are identified using vegetative and reproductive features.
5. Write a detailed note on floral formula and floral diagram of Fabaceae and Solanaceae.



UNIT 5.2

General account of the monocot families

5.2.1 Liliaceae: The Lily Family

Introduction: The family **Liliaceae**, commonly known as the *Lily Family*, is one of the best-known families of monocotyledonous flowering plants. It consists of about **15 genera and 600–800 species** distributed mainly in temperate and subtropical regions, with many species in Eurasia. Members are renowned for their **showy flowers**, making them popular ornamental plants, and some are valued for food or medicine. Historically, the family was much larger, but modern taxonomy has placed many genera into related families; nevertheless, Liliaceae remains an important and distinctive family.

Vegetative Characters: Most Liliaceae members are **perennial herbs** with **bulbs, corms, or rhizomes** used for storage and perennation. The stems are often short and underground, while aerial stems may be erect and unbranched. Leaves are typically **simple, alternate or basal in rosettes, parallel-veined**, and often **linear or lanceolate**. They are exstipulate (without stipules) and may have sheathing leaf bases. Because many members grow in seasonal climates, they have underground storage organs to survive adverse periods.

Inflorescence and Flowers: The inflorescence is usually a **raceme, umbel, or solitary terminal flower**. Flowers are **complete, bisexual, actinomorphic** (radially symmetrical), and **hypogynous** with a **superior ovary**.

- **Perianth:** Composed of **6 tepals** arranged in two whorls of three, often petaloid (showy and colored) with similar appearance in both whorls.
- **Androecium:** 6 stamens arranged in two whorls of three, with versatile anthers.
- **Gynoecium:** Tricarpellary, syncarpous, ovary superior, trilocular with axile placentation and numerous ovules; style simple with capitate stigma.

Floral Formula: $\text{♀} \oplus \text{P}_{3+3} \text{A}_{3+3} \text{G}_{(3)}$

Fruit and Seeds: The fruit is commonly a **capsule** that dehisces to release seeds, or sometimes a **berry** (as in *Smilax*). Seeds are often endospermic, containing food reserves to support seedling growth.

Pollination and Dispersal: Flowers are typically **entomophilous** (insect-pollinated), attracting pollinators with their bright tepals and

nectar. Many species are pollinated by bees, butterflies, or moths. Seeds are dispersed by various means—wind, gravity, or animals depending on the fruit type.

Economic Importance: The Liliaceae family has significant horticultural, nutritional, and medicinal importance:

Ornamentals: *Lilium* (true lilies), *Tulipa* (tulips), *Gloriosa* (glory lily) are prized for their beautiful flowers.

Food Plants: *Allium cepa* (onion) and *Allium sativum* (garlic), traditionally included in Liliaceae, are important vegetables and flavoring agents (modern taxonomy often places them in Amaryllidaceae). *Asparagus officinalis* (asparagus) is another edible shoot.

Medicinal Plants: *Colchicum autumnale* (source of colchicine used in medicine and plant breeding).

Others: Some, like *Aloe vera* (now placed in Asphodelaceae), are used in cosmetics and medicine.

Representative Genera: Important genera traditionally placed in Liliaceae include **Lilium** (lilies), **Tulipa** (tulips), **Gloriosa** (glory lily), **Asparagus** (asparagus), **Allium** (onion, garlic), and **Colchicum** (meadow saffron).

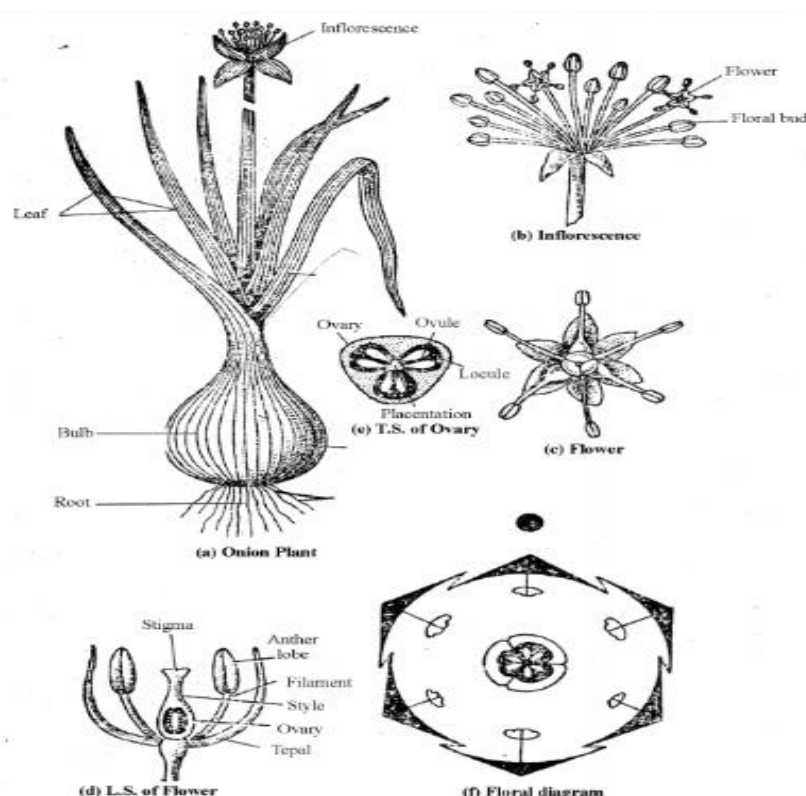


Fig. 5.13 Allium (onion)



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5.2.2 Poaceae: The Grass Family

Introduction: The family **Poaceae**, also known as **Gramineae** or the *Grass Family*, is one of the largest and most economically important families of flowering plants. It comprises about **780 genera and over 12,000 species** distributed worldwide, dominating grasslands, savannas, and cultivated fields. Members are mostly **herbs** adapted to a wide range of habitats. Poaceae includes the world's major cereal crops, making it the backbone of human civilization, animal husbandry, and ecological systems.

Vegetative Characters: Most members are **annual or perennial grasses** with jointed stems called **culms**, which are typically hollow except at the nodes. Stems are herbaceous, though in bamboos (*Bambusa*) they can be woody. Leaves are **alternate, distichous** (arranged in two rows), and **exstipulate**. Each leaf has a **sheath** encircling the stem and a **blade** extending outward, with a membranous or hairy **ligule** at the junction. Venation is **parallel**, and leaves often have silica bodies, making them rough to the touch and resistant to grazing.

Inflorescence and Spikelet Structure: The inflorescence is highly specialized, usually a **spike, raceme, or panicle** composed of units called **spikelets**. A spikelet consists of one or more **florets** subtended by two **glumes** (bracts) at the base. Each floret is enclosed by a **lemma** (outer bract) and **palea** (inner bract). The lemma may bear an awn. This unique spikelet structure is diagnostic of Poaceae.

Flowers (Florets): Flowers are highly reduced and specialized, usually **bisexual, incomplete, and actinomorphic**.

- **Perianth:** Represented by tiny scales called **lodicules** (usually 2 or 3) instead of petals and sepals.
- **Androecium:** Typically 3 stamens with large versatile anthers that swing freely in the wind.
- **Gynoecium:** Bicarpellary, syncarpous, superior ovary, unilocular with a single ovule; styles 2, feathery stigmas to catch wind-borne pollen.

Floral formula: $\text{♀} \oplus \text{P2 A3 G(2)}$

Fruit and Seeds: The fruit is a **caryopsis** (grain), a unique type of indehiscent fruit where the seed coat is fused with the fruit wall. This structure is typical of cereals such as rice, wheat, and maize. Seeds are rich in starch and stored food, making them essential for human and animal diets.

Pollination and Dispersal: Pollination in Poaceae is primarily **anemophilous** (wind-pollinated). The small, inconspicuous flowers lack nectar and bright colors, but produce abundant lightweight pollen. The feathery stigmas efficiently trap pollen grains. Seeds are dispersed by wind, animals, and sometimes water, depending on the species.

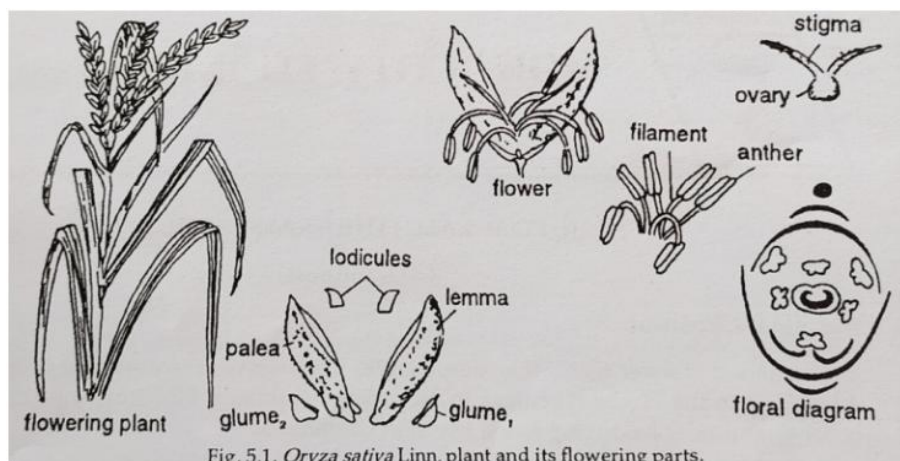


Fig. 5.1. *Oryza sativa* Linn. plant and its flowering parts.

Fig.5.14 Oryza

Summary

Economic Importance: The Poaceae family is the most important plant family for humans:

Cereals and Food Crops: *Oryza sativa* (rice), *Triticum aestivum* (wheat), *Zea mays* (maize/corn), *Hordeum vulgare* (barley), *Sorghum bicolor* (sorghum), *Avena sativa* (oats), *Pennisetum glaucum* (pearl millet).

Fodder Grasses: *Cynodon dactylon* (doob grass), *Saccharum* (sugarcane tops), *Panicum* species (guinea grass).

Sugar Production: *Saccharum officinarum* (sugarcane) is the major source of sugar and molasses.

Industrial Uses: *Bambusa* (bamboo) for construction, paper, and handicrafts; grasses for thatching, mats, and weaving.

Lawns and Ornamentals: Many grasses are used for turf in gardens and sports fields. **Representative Genera:** Important genera include *Oryza* (rice), *Triticum* (wheat), *Zea* (maize), *Saccharum* (sugarcane), *Bambusa* (bamboo), *Sorghum* (jowar), *Avena* (oat), *Cynodon* (doob grass), and *Panicum* (millets).

SELF ASSESSMENT QUESTIONS

Multiple Choice Questions (MCQs):

- Which of the following is a characteristic feature of dicots?
 - Parallel venation in leaves
 - Two cotyledons in seeds



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- c) Fibrous root system
- d) Scattered vascular bundles

Ans. b) Two cotyledons in seeds

2. The family Fabaceae is commonly known as:

- a) Sunflower family
- b) Mustard family
- c) Legume family
- d) Grass family

Ans. c) Legume family

3. Which of the following belongs to the Brassicaceae family?

- a) Pea
- b) Mustard
- c) Mango
- d) Cotton

Ans. b) Mustard

4. The Ranunculaceae family is known for:

- a) Leguminous plants
- b) Woody trees
- c) Herbs and ornamental flowers
- d) Grasses and cereals

Ans. c) Herbs and ornamental flowers

5. Which of the following is an economically important plant in the Euphorbiaceae family?

- a) Wheat
- b) Rubber
- c) Potato
- d) Apple

Ans. b) Rubber

6. A distinguishing feature of monocots is:

- a) Presence of two cotyledons
- b) Reticulate venation
- c) Parallel venation and fibrous root system
- d) Secondary growth in stems

Ans. c) Parallel venation and fibrous root system

7. Liliaceae family is characterized by:

- a) Compound leaves
- b) Flowers with six tepals
- c) Single-seeded fruits
- d) Absence of flowers



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Ans. b) Flowers with six tepals

8. Which of the following belongs to the Poaceae family?
- a) Rose
 - b) Rice
 - c) Cotton
 - d) Coffee

Ans. b) Rice

9. The Apiaceae family is important because it includes:
- a) Spices and medicinal plants like coriander and fennel
 - b) Timber-producing trees
 - c) Grains like wheat and maize
 - d) Fiber-producing plants

Ans. a) Spices and medicinal plants like coriander and fennel

10. Which monocot family is the most important for food production?
- a) Liliaceae
 - b) Poaceae
 - c) Acanthaceae
 - d) Rutaceae

Ans. b) Poaceae

Short Answer Questions:

1. What are the general characteristics of dicot plants?
2. Name three economically important plants from the Fabaceae family.
3. What is the significance of the Malvaceae family in agriculture?
4. How does the Solanaceae family contribute to human nutrition?
5. What are the major genera of the Rutaceae family?
6. List three economically important plants from the Liliaceae family.
7. What are the key differences between monocots and dicots?
8. How does the Poaceae family contribute to global food supply?
9. What is the economic importance of the Euphorbiaceae family?
10. Describe the role of the Apiaceae family in traditional medicine.

Long Answer Questions:



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1. Discuss the general characteristics and economic importance of dicot families.
2. Explain the features and major genera of the Fabaceae, Solanaceae, and Brassicaceae families.
3. Compare and contrast the Lamiaceae and Apiaceae families in terms of morphology and uses.
4. Describe the significance of the Poaceae family in agriculture and industry.
5. What are the major genera of the Liliaceae family, and how are they used?
6. Explain the economic importance of Rutaceae, Malvaceae, and Euphorbiaceae families.
7. How do monocots differ from dicots in terms of anatomy, reproduction, and economic significance?
8. Discuss the medicinal and industrial uses of plants from the Asclepiadaceae and Apocynaceae families.
9. Explain how flowering plant diversity contributes to ecosystem stability and human livelihood.
10. Describe the adaptations of monocots and dicots to different environments.

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