Evolution, Diversity and Classification of flowering plants

Feature image: A selection of angiosperms. Top row, from left to right: Tulip poplar (*Liriodendron tulipfera*), mayapple (*Podophyllum peltatum*), dwarf lake iris (*Iris lacustris*), and winter hazel (*Fothergilla*). Bottom row: Green milkweed (*Asclepias viridis*), echinacea (*Echinacea*), and clematis (*Clematis*). All images by E.J. Hermsen (DEAL).

SCBI602206 - Plant Diversity

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Learning objective

- **To be able to explain why angiosperms are the dominant form of plant life in most terrestrial ecosystems**

- **To be able to observe the differences and similarities in character among the species of the angiosperm.**

Outline

- ❖ **Apomorphy of Angiosperm**
- ❖ **Angiosperm origins**
- ❖ **Modern Classification of Angiosperms :The APG (Angiosperm Phylogeny Group)**
- ❖ **Monocot & Dicot**

Overview

- Angiosperms, or the flowering plants, are without doubt the most diverse group of modern plants. There may be over 290,000 species of angiosperms alive today, and they are thought to make up about 90% of the world's living embryophyte species (see here). Angiosperms are highly variable in form. They include herbs, shrubs, trees, vines, and succulents. They occur in a great many habitats, from forests, grasslands, and deserts, to aquatic and marine environments. Angiosperms comprise the great bulk of our economically important plants, including our most valuable food crops.

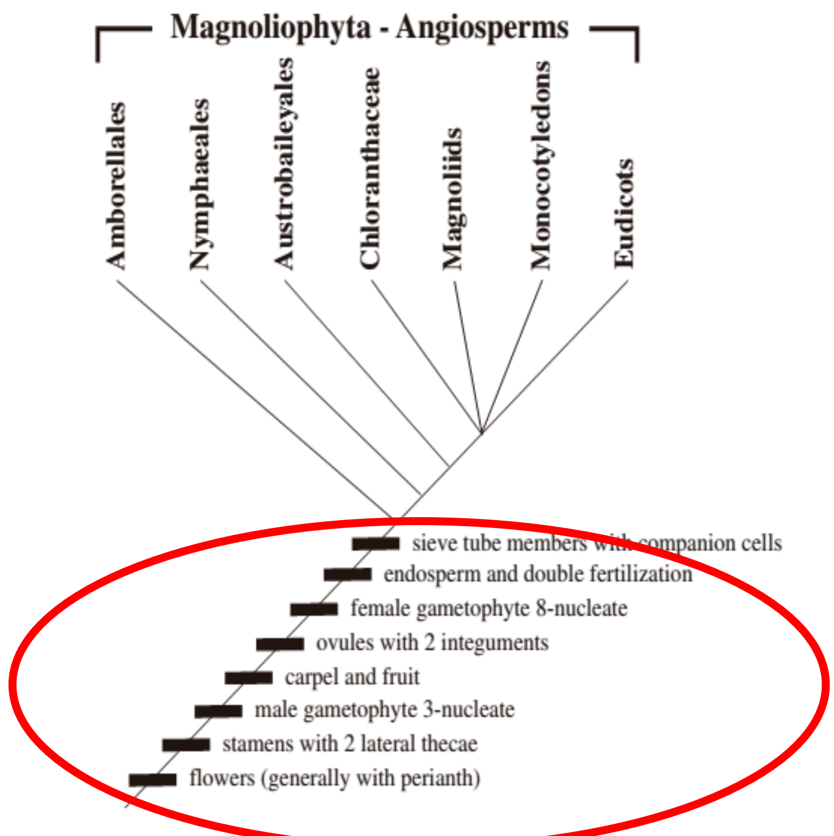
Angiosperm diversity. Left: Bluets (*Houstonia*), small herbs growing in the eastern North American forest. Second from left: Manzanita (*Arctostaphylos*), a small tree growing in an arid region of California, U.S.A. Third from left: Bittersweet (*Celastrus*), a vine. Right: Sacred lotus (*Nelumbo nucifera*), an aquatic plant. Credits: Manzanita by E.J. Hermsen & J.R. Hendricks (DEAL); bluets, bittersweet, and sacred lotus by E.J. Hermsen (DEAL).

The flowering plants, or angiosperms (also called Angiospermae, Magnoliophyta, or Anthophyta), are a monophyletic group currently thought to be the sister group to the gymnosperms

Apomorphy of angiosperms

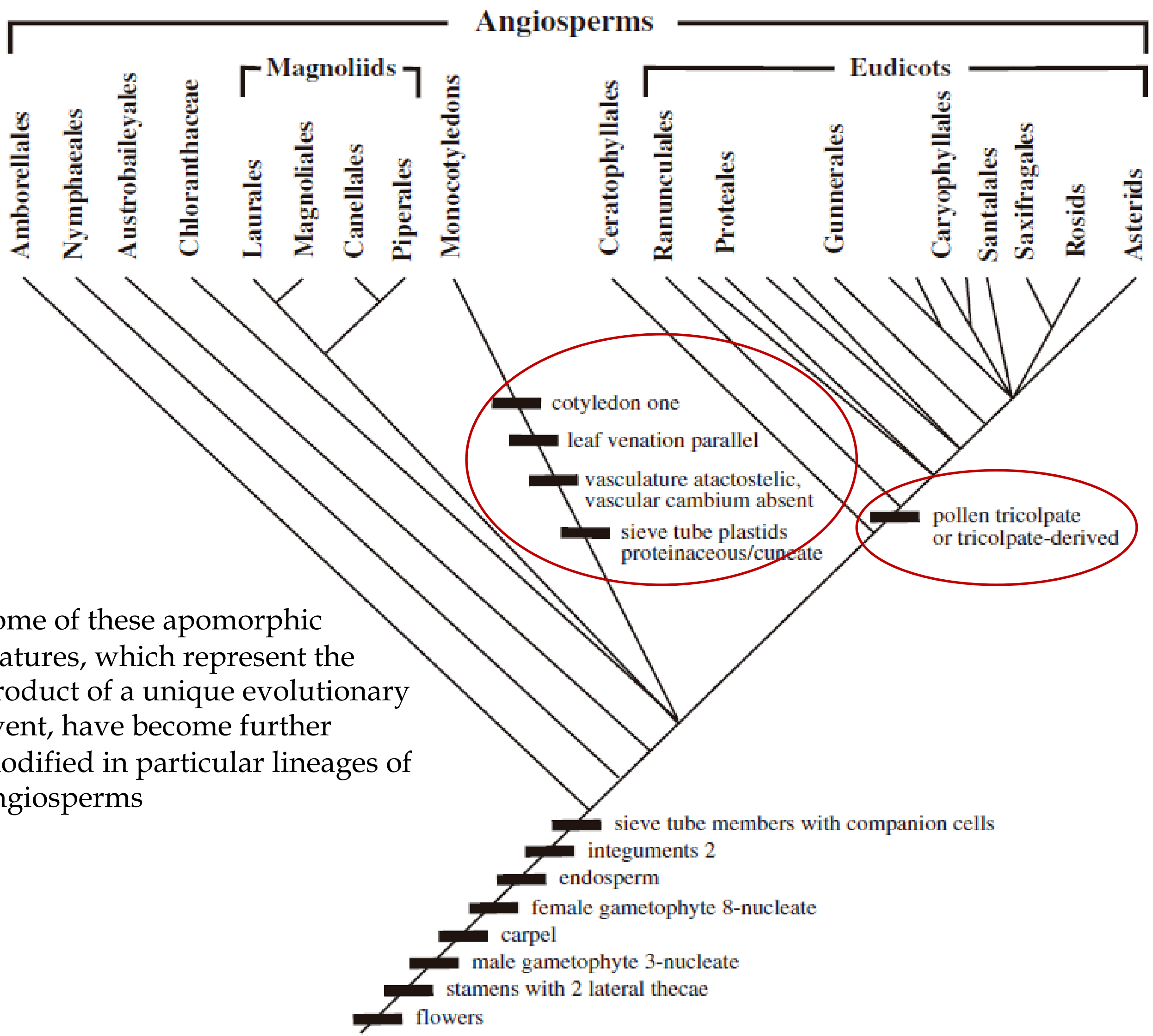
Several apomorphies distinguish the angiosperms from all other land plants (Figure 6.1):

(1) the flower, usually with an associated perianth; (
(2) stamens with two lateral thecae, each composed of two microsporangia;
(3) a reduced, 3-nucleate male gametophyte;
(4) carpels and fruit formation;
(5) ovules with two integuments; (
(6) a reduced, 8-nucleate female game- tophyte;
(7) endosperm formation; and
(8) sieve tube members.



Cladogram of the angiosperms, showing apomorphies and major taxonomic groups, the latter after APG II (2003).

Apomorphy of angiosperms



Some of these apomorphic features, which represent the product of a unique evolutionary event, have become further modified in particular lineages of angiosperms

FIGURE 7.1 Phylogenetic relationships of major angiosperm clades, from APG II, 2003, with selected apomorphies shown (see Chapter 6).

1. flower, usually with perianth

Angiosperm Apomorphies

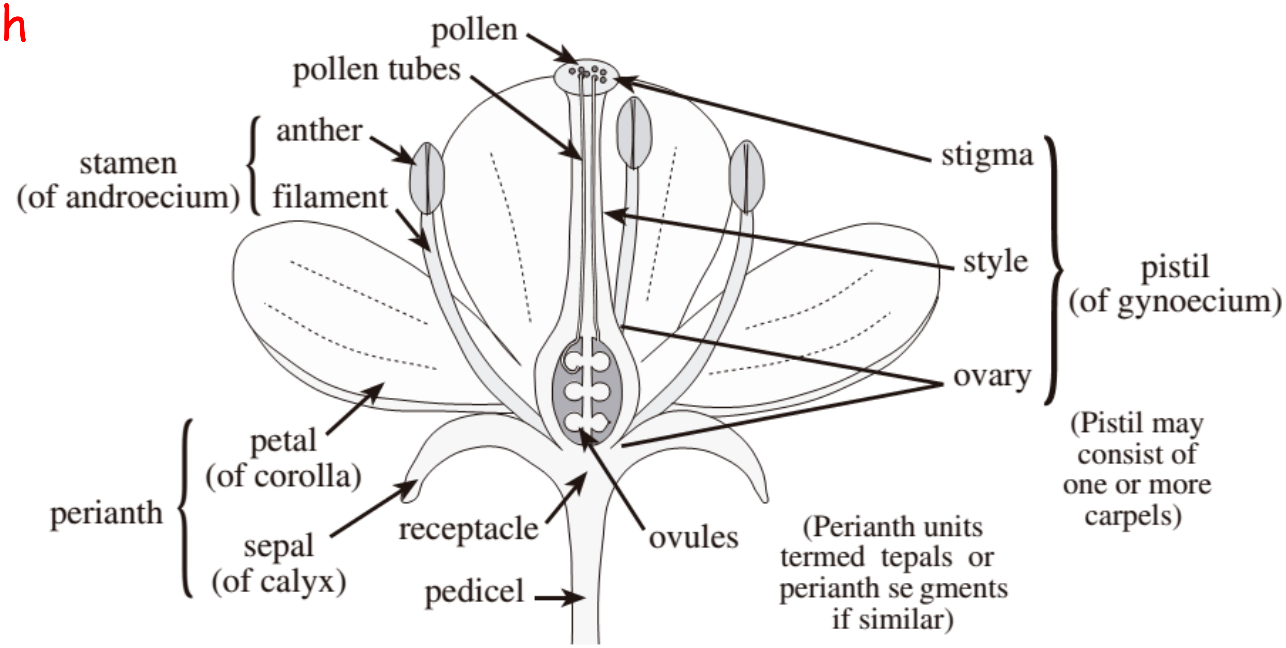


FIGURE 6.2 A typical (diagrammatic) ower, illustrating the parts.

Perhaps the most obvious distinguishing feature of angio- sperms is the **flower** (Figure 6.2). A flower can be defined as a *modified*, *determinate shoot* system bearing one or more **stamens**, collectively called the **androecium**, and/or one or more **carpels** (making up one or more **pistils**), collectively called the **gynoecium** (see later discussion). Most angiosperm flowers are **bisexual** (**perfect**), containing both stamens and carpels, but some are **unisexual** (**imperfect**), having only stamens or carpels. In addition, most (but not all) flowers have a **perianth**, consisting of modified leaves at the base of the shoot system.

1. flower, usually with perianth

Angiosperm Apomorphies

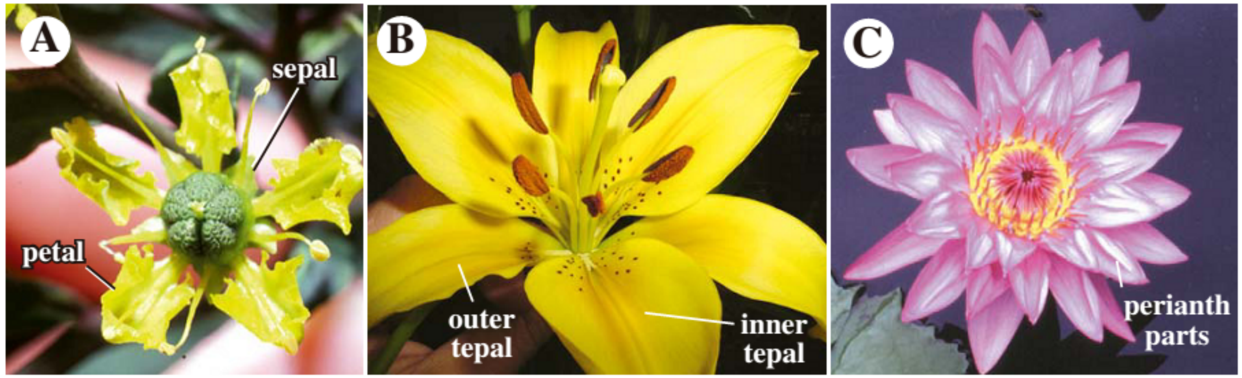


FIGURE 6.3 Various perianth types in owers. **A.** Perianth of two whorls, dissimilar in appearance: a calyx of sepals and a corolla of petals (*Ruta*). **B.** Perianth of two whorls, similar in appearance: outer tepals and inner tepals (*Lilium*). **C.** Perianth undifferentiated, spiral (*Nymphaea*).

The perianth of a flower both protects the other floral parts during floral development and functions as an attractant for pollination. Most flowers have a perianth of *two* discrete whorls or series of parts: an outer **calyx** and an inner **corolla** (Figure 6.3A). The calyx is generally green and photosynthetic, composed of leaf-like **sepals** or (if these are fused) of **calyx lobes**. The corolla is typically colorful, showy, and odoriferous and is composed of individual **petals** or (if these are fused) of **corolla lobes**. However, in some flowering plants, there are two whorls of parts, but the outer and inner whorl of perianth parts are not otherwise differentiated, resembling one another in color and texture. The term **tepal** is often used for such similar perianth parts, and one may refer to **outer tepals** and **inner tepals** for the two whorls (Figure 6.3B). More rarely, the perianth may consist of a single whorl (this usually called the calyx, by tradition) or of three or more discrete whorls (see Chapter 9). Finally, the perianth of some flowers consists of spirally arranged units that grade from sepal-like structures on the outside to petal-like structures on the inside, but with no clear point of differentiation between them; in this case, the units may be termed **tepals**, **perianth parts**, or **perianth segments** (Figure 6.3C).

Angiosperm Apomorphies

2. stamens with 2 lateral thecae,

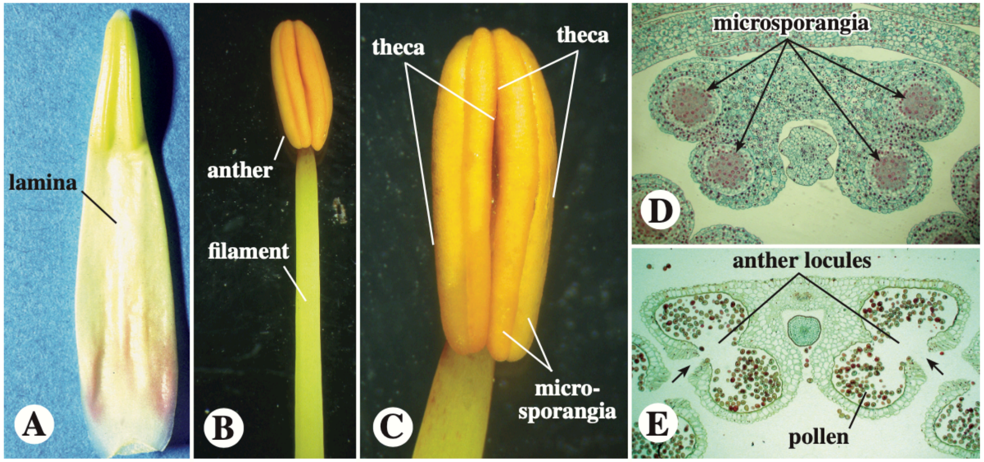


FIGURE 6.7 Stamen morphology. **A.** Laminar stamen, *Nymphaea*. **B,C.** Filamentous stamen, *Aloe*. Note anther composed of two thecae, each with two microsporangia. **D.** Young anther in cross-section, showing four microsporangia. **E.** Cross-section of older anther at time of dehiscence. Note that walls between adjacent microsporangia of each theca have broken down. Dehiscence line indicated by arrows.

A distinctive apomorphy for the angiosperms is the **stamen**, the male reproductive organ of a flower.

- Stamens are interpreted as modified microsporophylls, modified leaves that bear microsporangia.
- Microsporangia produce microspores, which develop into pollen grains.
- Some stamens have a laminar (leaf-like) structure, to which the anther is attached or embedded (Figure 6.7A).
- However, the stamens of most flowering plants have two parts: a stalk, known as a **filament**, and the pollen bearing part, known as the **anther** (Figure 6.7B).
- Some stamens lack a filament (or lamina), in which case the anther is **sessile**, directly attached to the rest of the flower.
- The angiosperm anther is a type of synangium, a fusion product of sporangia.
- Anthers are unique in (ancestrally) containing two pairs of microsporangia, usually arranged in a bilateral symmetry (i.e., having two mirror image halves).
- Each pair of microsporangia is typically located within a discrete half of the anther called a **theca** (plural, **thecae**; Figure 6.7C). Thus, such an anther consists of two thecae (termed **bithecal**), each theca having two microsporangia for a total of four (termed **tetrasporangiate**; Figure 6.7D).
- At maturity, the two microsporangia of a theca typically coalesce into a single, contiguous chamber, called the **anther locule**; each theca then opens to the outside by a specific dehiscence mechanism, releasing the pollen (Figure 6.7E).
- (Note that anthers of some angiosperms are secondarily reduced to a single theca, known as **monothecal** or **bisporangiate**, a dis-tinctive systematic character.

Angiosperm Apomorphies

3. reduced 3-nucleate male gametophyte

Another apomorphy for the angiosperms is a **reduced, three- celled male gametophyte** (Figure 6.8).

- No other plant group has a male gametophyte so reduced in cell number.
- After each **microspore** is formed by meiosis within the microsporangium, its single nucleus divides mitotically to form two cells: a **tube cell** and a **generative cell** (Figure 6.8A,B).
- The generative cell divides one time, producing **two sperm cells** (Figure 6.8A). Pollen grains are shed in either a two- or three-celled condition, depending on whether the generative cell division occurs before or after the pollen grains are released. If pollen is released as two-celled, then the generative cell divides within the pollen tube as it travels down the style (Figure 6.8A). The pollen grains of angiosperms, like those of gymno- sperms, "germinate" during development, meaning that an elongate **pollen tube** grows out of the pollen grain wall, a condition known as **siphonogamy** (Figure 6.8A,C,D).

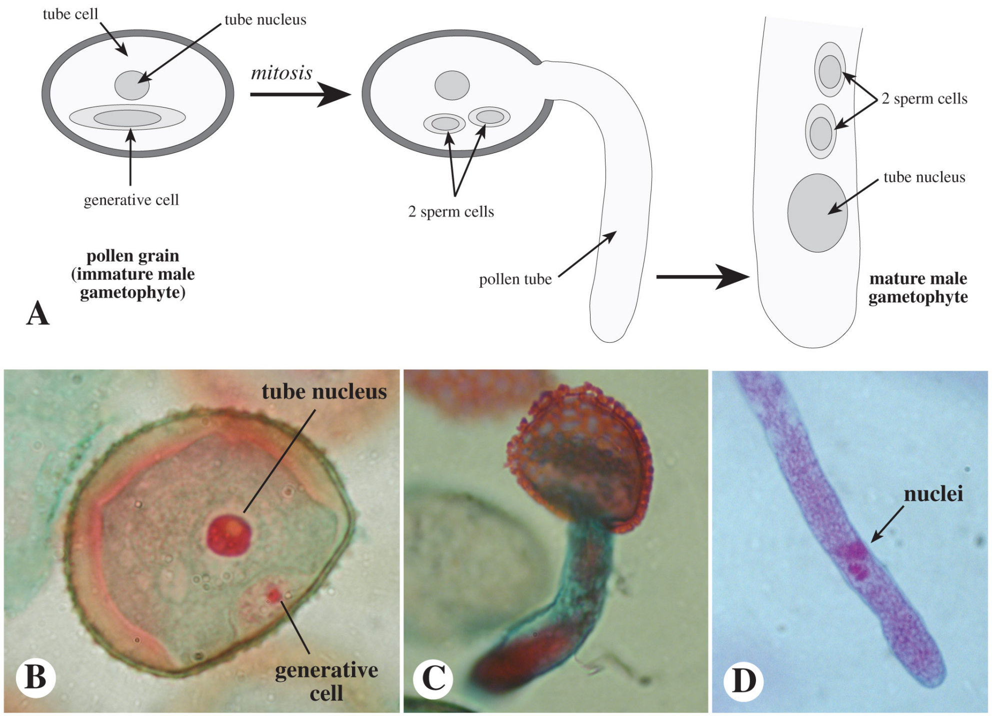


FIGURE 6.8 Angiosperm male gametophyte. **A.** Development of reduced 3-nucleate male gametophyte from pollen grain. **B.** Mature binucleate pollen grain, with tube nucleus and generative cell. **C.** Germinating pollen grain, forming pollen tube. **D.** Tip of pollen tube, housing nuclear material (nuclei types unclear in this image).

Angiosperm Apomorphies

4. carpels and fruit formation
   - conduplicate (inwardly folded longitudinally & along the central margin) megasporophyll bearing 2 adaxial rows of ovules
   - carpel body encloses seed (angiosperm name origin)

A major apomorphy of angiosperms is the carpel.

- Recall that a megasporophyll is a modifed leaf that bears megasporangia, which in the seed plants are components of the ovules and seed
- The term gynoecium is the totality of female reproductive structures in a flower, regardless of their structure.
- Thus, a carpel may be alternatively defined as a unit of the gynoecium.
- The gynoecium is composed of one or more pistils. Each pistil consists of a basal ovary, an apical style (or styles), which may be absent, and one or more stigmas, the tissue receptive to pollen grains
- A pistil may be equivalent to one carpel (in which case, it may be termed a simple pistil) or composed of two or more, fused carpels (The position of one or more ovules and the fusion of one or more carpels determine various placentation types

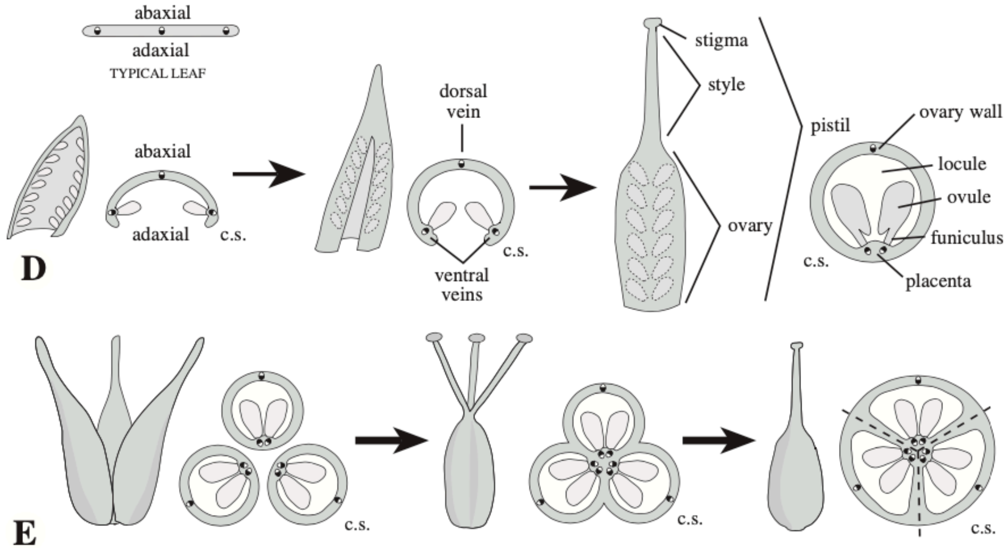


Figure 6.9. The carpel, an apomorphy of the angiosperms. **D.** Diagram of carpel development from early stages to mature ovary, adaxial side below. Note dorsal and ventral veins (black=xylem; white=phloem), the latter becoming inverted. **E.** Diagram illustrating evolutionary sequence of carpel fusion (dashed lines=carpel boundaries).

Angiosperm Apomorphies

5. ovules with 2 integuments
    - bitegmic with micropyle at distal end

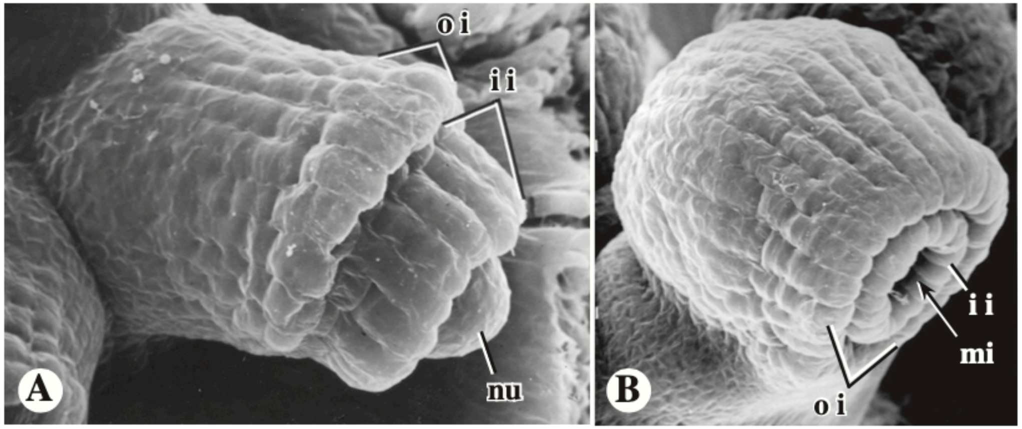


FIGURE 6.11 Bitegmic ovule, the ancestral condition of the angiosperms. **A.** Young ovule, showing intiation of inner integument (ii) and outer integument (oi), both growing around the nucellus (nu). **B.** Older ovule, in which inner and outer integuments have enveloped the nucellus, forming a micropyle (mi).

- A unique apomorphy of angiosperms is the growth of two integuments during ovule development, the ovules known as bitegmic (Figure 6.11).
- All nonflowering seed plants have ovules with a single integument, termed unitegmic.
- The two integuments of angiosperms usually completely surround the nucellus, forming a small pore at the distal end; this opening, the micropyle, is the site of pollen tube entrance.
- Both of the integuments of angiosperm ovules contribute to the seed coat. The two integuments typically coalesce during seed coat development, but may form anatomically different layers.

Angiosperm Apomorphies

6. reduced, 8-nucleate female gametophyte

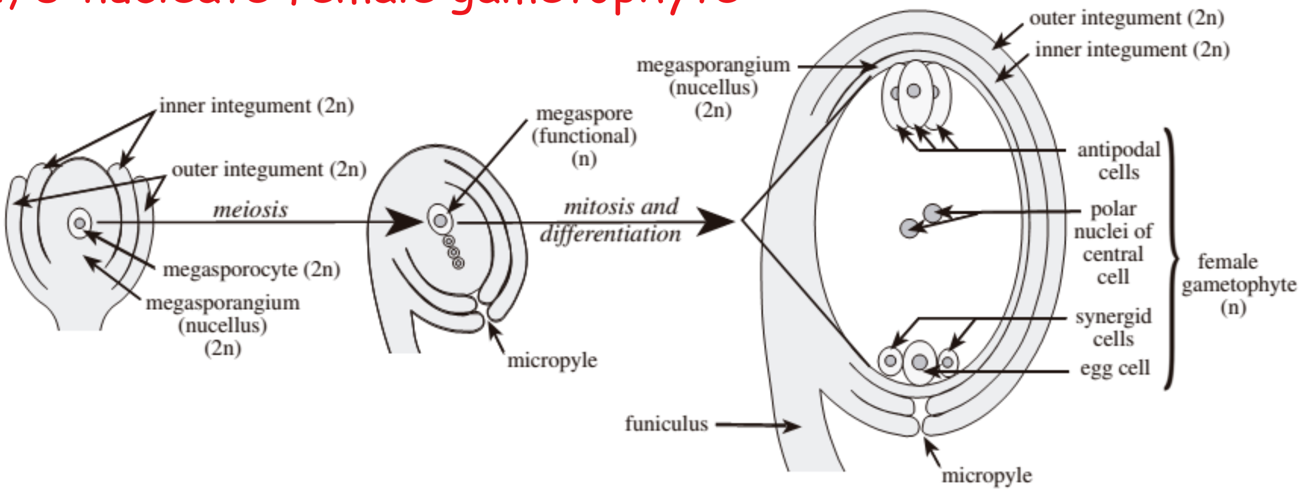


FIGURE 6.12 Angiosperm ovule development and morphology. Note meiosis of megasporocyte, producing four haploid megaspores, one of which undergoes mitotic divisions and differentiation, resulting in an 8-nucleate female gametophyte.

Several novelties of the angiosperms have to do with the evolution of a specialized type of ovule and seed. A major apomorphy of angiosperms is a **reduced female gametophyte**.

- As in other seed plants, a single megasporocyte within the megasporangium (nucellus) divides meiotically to form four haploid megaspores (Figure 6.12).
- The female gametophyte typically generates from only one of these megaspores (Figure 6.12), with a few exceptions in which others may contribute.
- In the great majority of angiosperms the megaspore divides in a sequence of three mitotic divisions, resulting in a total of eight haploid nuclei.
- Further differentiation usually results in an arrangement of these eight nuclei into seven cells, a pattern known as the *Polygonum* type (Figures 6.12).
- In the micropylar region three cells develop: an **egg** cell flanked by two **synergid cells**.
- Egg plus synergids is sometimes called the "egg apparatus."
- In the **chalazal** region, which is opposite the micropyle, three **antipodal cells** form.
- The remaining volume of the female gametophyte is technically a single cell, called the **central cell**, which contains two **polar nuclei**.

Angiosperm Apomorphies

6. reduced, 8-nucleate female gametophyte:
   - evolution of female gametophyte

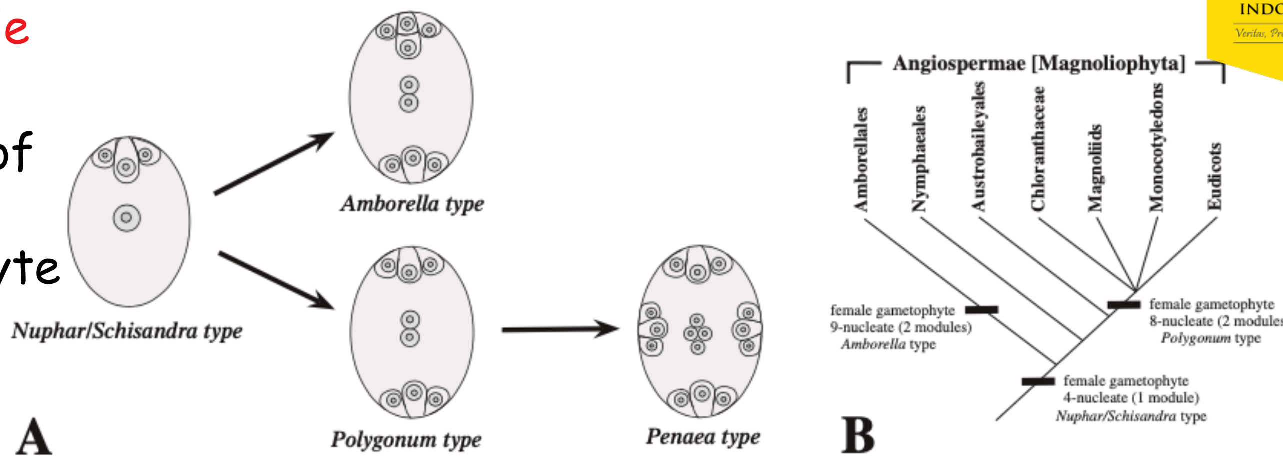


FIGURE 6.14 **A.** Modular hypothesis of female gametophyte evolution. The monosporic, 4-nucleate *Nuphar/Schisandra* type may represent the ancestral condition in the angiosperms, independently giving rise to the *Amborella* type and *Polygonum* type by duplication of the basic 4-nucleate module. **B.** Cladogram of angiosperms, showing evolutionary changes according to this modular hypothesis. Note that the *Polygonum* type is derived within the angiosperms. (After Friedman and Williams, 2004.)

- A recent theory of female gametophyte evolution suggests that the ancestral condition of angiosperms was not the common monosporic, 8-nucleate, 7-celled *Polygonum* type, but was instead a monosporic, 4-nucleate and celled condition found in virtually all Nymphaeales and Austrobaileyales termed the ***Nuphar/Schisandra* type** (Figure 6.14A).

- This 4-nucleate condition, having one polar nucleus in a central cell and 3 cells (the egg apparatus) at the micropylar end could represent an ancestral *module*. This module would sub- sequently have been doubled (a third sequence of mitotic divisions) to yield the common ***Polygonum* type** (Figure 6.14A) or quadrupled to yield something like the 16-nucleate ***Penaeid* type** (Figure 6.14A).

- In fact, the most basal angiosperm, *Amborella trichopoda,* has a modified type of female gametophyte, being 9-nucleate and 8-celled via an extra mitotic division in the egg apparatus producing a third synergid cell; this type has been termed the ***Amborella* type** and may have evolved independently of the common *Polygonum* type.

- A simplified cladogram of angiosperm relation- ships (Figure 6.14B) shows this scenario, with the 4-nucleate condition *Nuphar/ Schisandra* type primitive and the 8-nucleate *Amborella* and *Polygonum* types derived.

Angiosperm Apomorphies

7. endosperm formation
   - product of double fertilization
     - zygote = 1 sperm + egg
     - endosperm = 1 sperm + polar nuclei

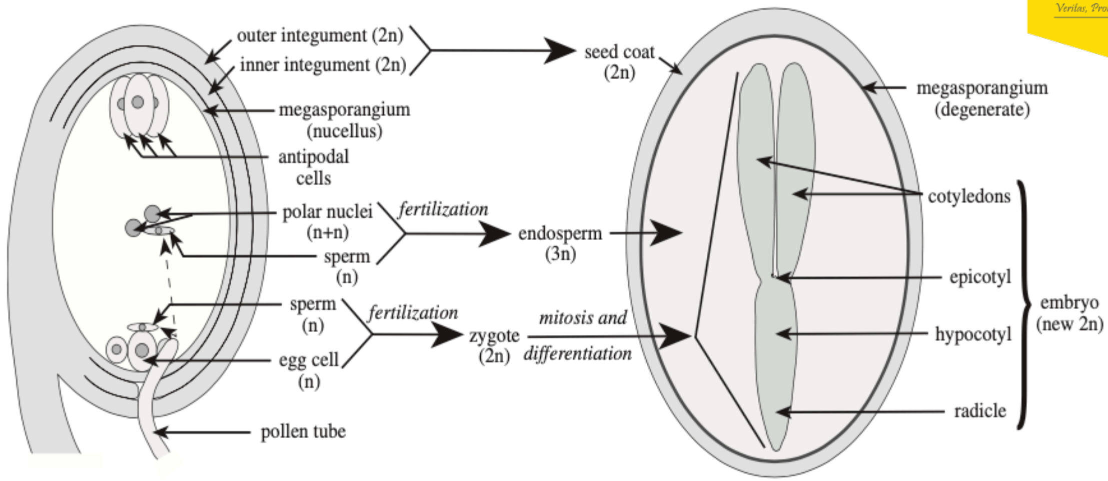


FIGURE 6.15 Angiosperm seed development and morphology. Note fertilization of egg, forming zygote and embryo, and fertilization of polar nuclei, forming triploid endosperm.

Another major apomorphy of the angiosperms is the presence of **endosperm**.

- Endosperm is the product of **double fertilization**.
- When the pollen tube enters the micropyle of the ovule, it penetrates one of the synergid cells and releases the two sperm cells into the central cell of the female gametophyte (Figure 6.15).
- One sperm cell migrates toward and fuses with the egg cell to produce a diploid **zygote**.
- The other sperm cell fuses with the two polar nuclei to produce a triploid, or 3n, **endosperm cell**.
- This endosperm cell then repeatedly divides by mitosis, eventually forming the **endosperm**, a mass of outer integument (2n), inner integument (2n), megasporangium (nucellus) , tissue that generally envelopes the embryo of the seed (Figure 6.15).
- Endosperm replaces the female gametophyte as the primary nutritive tissue for the embryo in virtually all angiosperms, containing cells rich in carbohydrates, oil, or protein.

Angiosperm Apomorphies

8. sieve tube members
    - sieve plates – contain pores at end walls larger than lateral pores
    - sieve cells are primitive sugar-conducting cells

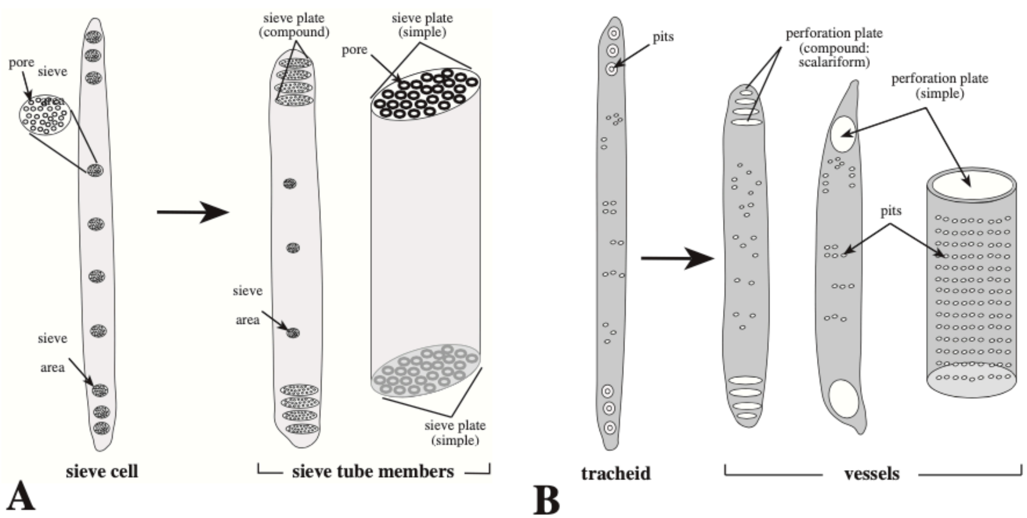


FIGURE 6.16 **A.** Evolutionary change from sieve cells (left) to sieve tube members, the latter an apomorphy of the angiosperms. **B.** Evolution of vessels in the angiosperms. Note transformation from imperforate tracheid to vessels with perforation plates. Trends within the angiosperms include change from elongate vessels with scalariform perforation plate to short vessels with simple perforation plates.

Angiosperms are unique (with minor exceptions) in having **sieve tube members** as the specialized sugar-conducting cells (Figure 6.16A).

- Sieve cells (and associated albuminous cells) are the primitive sugar-conducting cells and are found in all nonflowering vascular plants.
- Sieve tube members (and associated companion cells) were evolutionarily modified from sieve cells and are found only in flowering plants.
- Sieve tube members differ from the ancestral sieve cells in that the pores at the end walls are differentiated, being much larger than those on the side walls. These collections of differentiated pores at the end walls are called **sieve plates**.
- Sieve plates may be either compound (composed of two or more aggregations of pores) or simple (composed of one pore region).
- Parenchyma cells associated with sieve tube members are called **companion cells**.
- Companion cells function to load and unload sugars into the cavity of sieve tube members.
- Unlike the similar albuminous cells of gymnosperms, companion cells are derived from the same parent cell as the conductive sieve tube members.
- The adaptive significance of sieve tube members over sieve cells is not clear, though they may provide more efficient sugar conduction.

Angiosperms origin

Archaefructus 130 mya northern China

Darwin called the origin of the angiosperms an **"abominable mystery"**.

- The evolution of angiosperms remains a mystery to this day, although great progress has been made in recent years solving this mystery using a combination of fossil evidence, molecular data, and the discovery of the primitive angiosperm ***Amborella***.
- Flowering plants evolved sometime during the **Cretaceous**, approximately 140 million years ago, while the dinosaurs were at their peak.
- The earliest definitive flowers occur slightly later in the fossil record, as early as 130 million years ago. These early flowering plant fossils can largely be assigned to recognizable, extant groups.

  However, no fossils showing a transition from gymnosperm to angiosperm have been discovered. This makes the origin of the angiosperms mysterious.
- Angiosperms quickly became the dominant plants, although gymnosperms continued to rule in cold, dry, or sandy habitats, as they still do today.
- Regardless of the origin of the angiosperms, by the end of the Cretaceous (65-70 mya) most flowering plant families had evolved.

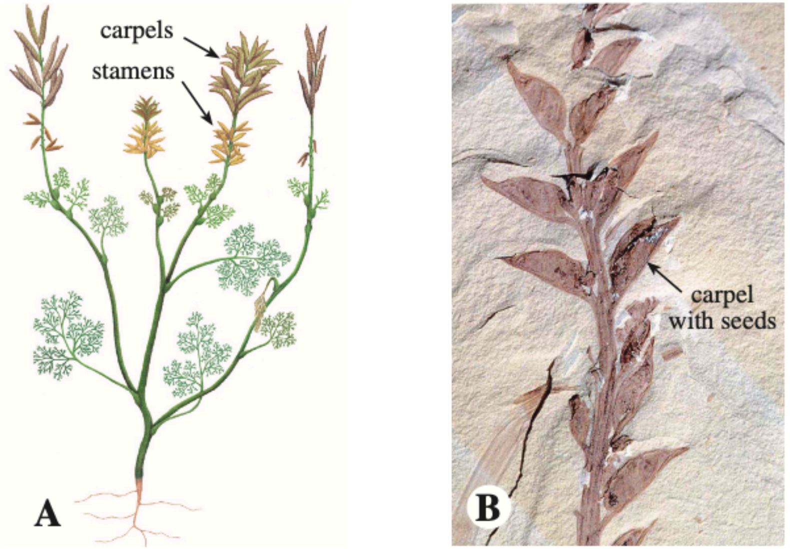


FIGURE 6.19 *Archaefructus*. **A.** Reconstruction of *Archaefructus sinensis*, showing reproductive axis bearing stamens proximally and carpels distally. (Contributed by K. Simons and David Dilcher (©).) **B.** Fossil impression of carpel units of *Archaefructus lianogensis*. (Contributed by David Dilcher (©) and Ge Sun.)

The most primitive flowering plants were once called "dicots," but we now know that this term is not monophyletic. Several groups have been removed and placed in separate taxa.

- The earliest known angiosperm, a fossil discovered in China, is the appropriately named *Archaefructus*.
- It was a marsh-dweller, with its roots in muddy sludge
  It had highly dissected, feathery leaves
  It had very simple versions of angiosperm stems, roots, etc.
  It was herbaceous
  Its flowers were small, but its many stamens might have attracted pollinators.
- ...suggesting that these characters could be primitive with respect to all angiosperms.

Angiosperms origin

However, the details of angiosperm evolution from a gymnosperm precursor are not clear. One problem is what to call an angiosperm. Many angiosperm features cited earlier, such as a reduced male gametophyte, reduced female gametophyte, and double fertilization with triploid endosperm, are microscopic and cytological and would be unlikely to be preserved in the fossil record. Cladistic analyses of extant angiosperms may help elucidate the features possessed by the common ancestor of the flowering plants. Given this, we might expect to find at least some of these features in the closest fossil relatives of the angiosperms.

Based on recent cladistic studies, *Amborella trichopoda* of the Amborellales (Figure 6.1) is accepted as the best hypothesis for the most basal angiosperm lineage.

Amborella lacks vessels and has unisexual flowers with a spiral perianth, laminar stamens, and separate carpels. However, other, near-basal lineages of flowering plants vary in these features, making an assessment of the characteristics of the common ancestor of the angiosperms unclear.

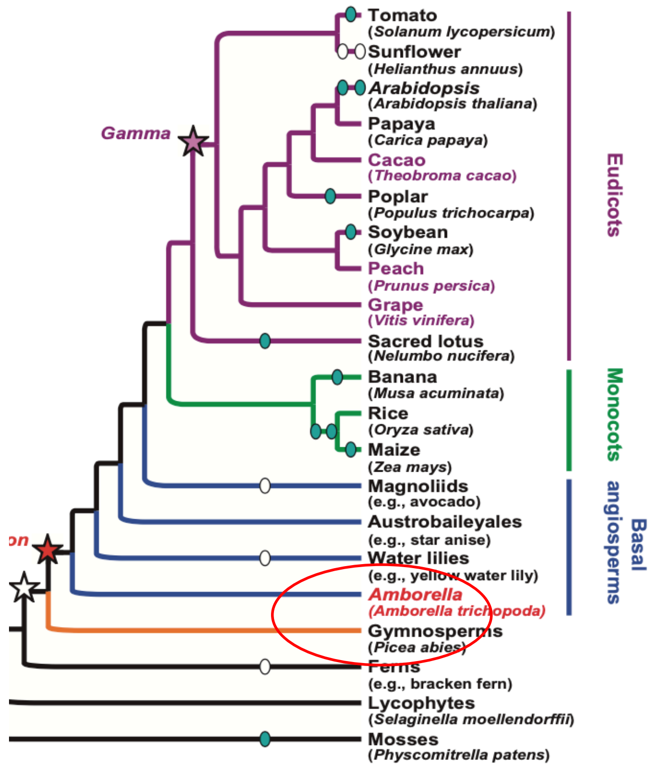


Fig. 1. *Amborella* is sister to all other extant angiosperms. An overview of land plant phylogeny is shown, including the relationships among major lineages of angiosperms. Representatives with sequenced genomes are shown for most lineages (scientific names in parentheses); however, basal angiosperms (all of which lack genome sequences except for *Amborella*) and nonflowering plant lineages are indicated by their larger group names. Hypothesized polyploidy events in land plant evolution are overlaid on the phylogeny with symbols. The red star indicates the common ancestor of angiosperms and the evolutionary timing of the *epsilon* WGD (7). The evolutionary timing of *zeta* (7) and *gamma* (26, 27, 82) polyploidy events are shown with empty and purple stars, respectively. The peach, cacao, and grape genomes (purple text) were used with the *Amborella* genome to reconstruct the gene order in the pre-*gamma* core eudicot (Fig. 2C). Additional polyploidy events are indicated with ellipses. Events supported by genome-scale synteny analyses are filled, whereas those supported only with frequency distributions of paralogous gene pairs (Ks) or phylogenomic analyses are empty (34–37, 83, 84).

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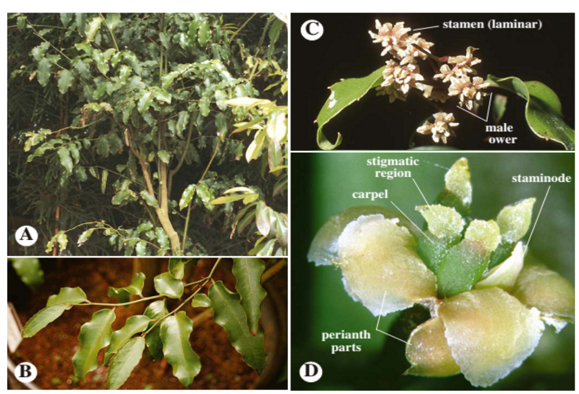


a trichopoda. **A.** Whole plant, in cultivation. **B.** Close-up of leaves. **C.** Male showing spiral perianth and apocarpous gynoecium. (A and C, courtesy of f California-Santa Cruz; D, courtesy of Sandra K. Floyd.)

The living anthophytes that retain the most archaic characters are found in New Caledonia. Of these, the most primitive is *Amborella trichopoda*, the only species in the most primitive anthophyte family, Amborellaceae. It's a short, evergreen shurb that has undifferentiated perianth parts (no distinct petals or sepals). It's dioecious, with separate sexes, and having relatively primitive sporophylls. It produces small, red fruits (drupes, which you'll meet later) and it's seeds have resin deposits reminiscent of the more primitive seed plants.

Amborellaceae - A Unique Living Fossil

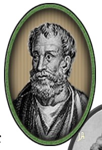
Classification of Angiosperms

History of Plant classification

PERIOD OF ANCIENTS

Theophrastus (370-285 BC)

Greek Philosopher. Book-*Enquiry into Plants* - 10 vols. Plants are classified according to their modes of generation, their localities, their sizes, and according to their practical uses. Covered about 500 different kinds of plants with common names.



Pliny the Elder (AD 23-79)

Gaius Plinius Secundus was a Roman naturalist. *Historia Naturalis* (AD 77) - a 37 volume work- about the universe, plants and animals. 9 volumes for med-plants.

Dioscorides (40-90 AD)

A Greek physician, pharmacologist and botanist, the author of *De Materia Medica*—a 5-volume encyclopedia about herbal medicine and related medicinal substances (a pharmacopeia), that was widely read for more than 1,500 years. In *Materia Medica,* there are about 600 plant species and their uses.

- **Period of Ancients: to ca. 1500 AD**
- **Period of Herbalists: 1500-ca. 1580**
- **Period of Mechanical Systems: 1580-ca. 1760**
- **Period of Natural Systems: 1760 to ca. 1880**
- **Period of Phylogenetic Systems: 1880 to date.**

PERIOD OF HERBALISTS

- Herbal means medicinal plants. Fifteenth and 16th century botany experienced a great general awakening in the field of medicine and classification.
- Herbalists include Otto Brunfels (1464-1534) and Jerome Bock (1498-1554).
- Many plant genera names-commemorate herbalist's names. E.g. *Brunfelsia* - Brunfels, *Clusia* - Charles L'Ecluse.

PERIOD OF MECHANICAL SYSTEMS

- During 16th and 17th century the science of botany developed as an independent discipline.
- *Gaspard Bauhin* (1560-1624)

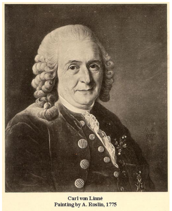
  A Swiss botanist- wrote *Pinax theatri botanici* (1623)- included about 6000 different kinds of plants.
- Carolus Linnaeus or Carl Linnaeus or Carl von Linne (1707-1778)

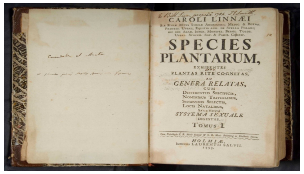
Father of modern taxonomic botany and zoology. 1730- *Hortus Unpandicus*, an enumeration of plants in Uppsala Botanic Garden. In revised edition of the book in 1732 he arranged the plants according to his own system, his so-called sexual system.

1735-*Systema Naturae* -classified plants, animals and minerals.

1736- *Fundamenta Botanica*.

1737 he published 4 books including *Critica Botanica* and *Genera Plantarum*. He proposed his sexual system of classification in *Genera plantarum* and provided descriptions for 935 genera.





PERIOD OF NATURAL SYSTEMS

During this period plants were classified based on their relationships and plants that looked alike were kept together.

Michel Adanson (1727-1806) **- French-*Families des Plantes* (1763). He emphasized equal weighing of characters and believed that all organs should be taken into account. Adanson is considered as "Grand Father of Numerical Taxonomy".**

de *Jussieu* (France) family.

- **Antonie (1686-1758), Bernard (1699-1996), Joseph (1704-1779) and Antonie Laurent (1748-1836).**

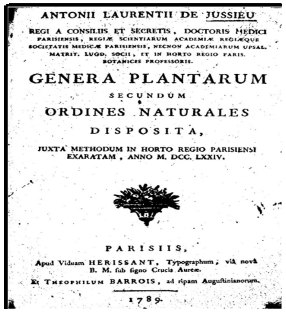
Antonie Laurent de Jussieu-published *'Genera Plantarum'* (1789).

This is the first major work to be natural in its approach. He divided the flowering plants into 15 classes-100 natural orders corresponding to most major families.

- **GEORGE BENTHAM & JOSEPH DALTON HOOKER**

  ***Genera Plantarum* (1863-1885)**

  202 families



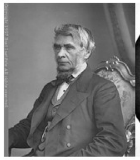
ANTONII LAURENTII DE JUSSIEU

REGI A CONSILIIS ET SECRETIS, DOCTORIS MEDICI PARISIENSIS, REGIÆ SCIENTIARUM ACADEMIÆ REGIÆQUE SOCIETATIS MEDICÆ PARISIENSIS, NECNON ACADEMIARUM UPSAL. MATRIT. LUGD. SOCII, ET IN HORTO REGIO PARIS. BOTANICES PROFESSORIS.

GENERA PLANTARUM SECUNDUM ORDINES NATURALES DISPOSITA,

JUXTA METHODUM IN HORTO REGIO PARISIENSI EXARATAM, ANNO M. DCC. LXXIV.

PARISIIS,
Apud Viduam HERISSANT, Typographum, via nova B. M. sub signo Crucis Aureæ.
Et THEOPHILUM BARROIS, ad ripam Augustinianorum.
1789.



George Bentham 1800-1884

Joseph Hooker 1817-1911

History of Plant classification

PERIOD OF PHYLOGENETIC SYSTEMS

The theory of Evolution proposed by Darwin in 1858 influenced taxonomy in many ways.

Post Darwinian systems can be broadly categorized into two groups: the Englerian School and the Ranalian school.

The Englerian School **considered simplicity as primitive and complexity as advanced and is based on the concept of progressive evolution.**

The Ranalean School **considered the Ranales group as the primitive and evolution proceeded in both progressive and retrogressive manner.**

ENGLERIAN SCHOOL

Believed Monocots are primitive.

***August Wilhelm Eichler* (1839-1887) – German-*Bluthendiagramme* (1875-1878).**

***Adolf Engler* (1844-1930) -in collaboration with *Karl Prantl* (1849-1893) presented a 20 volume work *Die Naturlichen Planzefamilien* (1897-1915).**

Adolph Engler 1844-1930   Karl Prantl 1849-1893

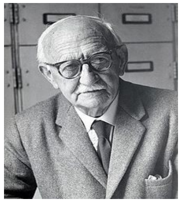
Englerian school

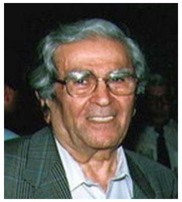
unisexual flowers, the most primitive

ADOLF ENGLER & KARL PRANTL

- *Die natürlichen Pflanzenfamilien* (first edition, 1887-1915)
- 288 vascular **plant** families

THE RANALIAN SCHOOL





Charles Edwin Bessey (1845-1915)- Bessey's Cactus

John Hutchinson (1884-1972)-2-volume work- *The Families of Flowering Plants* (1973)-328 families

Armen L. Takhtajan (1910-1997) Komarov Botanical Institute, Leningrad

Diversity and Classification of Flowering Plants (1997)-592 families

Arthur Cronquist New York Botanical Garden

An integrated system of classification of flowering plants (1981)- 388 families

The Evolution and Classification of Flowering Plants (1988) - 389 families

APG CLASSIFICATION

UNIVERSITAS INDONESIA
Veritas, Probitas, Iustitia

- **With the rapid advances in the field of molecular research with respect to DNA sequencing over the past three decades provided new datasets for classifying angiosperms more precisely.**

- **With the efforts of two international groups of systematic botanists from Royal Swedish Academy of Sciences and Missouri Botanical Garden, a new classification has been proposed under the umbrella of Angiosperm Phylogeny Group in 1998.**

- **With the efforts of 29 botanical systematists around the world, APGC was proposed.**

- **APG relies on the synthesis of information from the disciplines of morphology, anatomy, embryology, phytochemistry and more strongly on molecular studies with reference to:**

  DNA sequences of two chloroplast genes (cpDNA) and one gene coding for ribosomes (nuclear ribosomal DNA).

  - ***atpB* (1450bp)**
  - ***rbcL* (1428bp)**
  - **18S r *DNA* (1855bp)**

  - a total of 4733bp

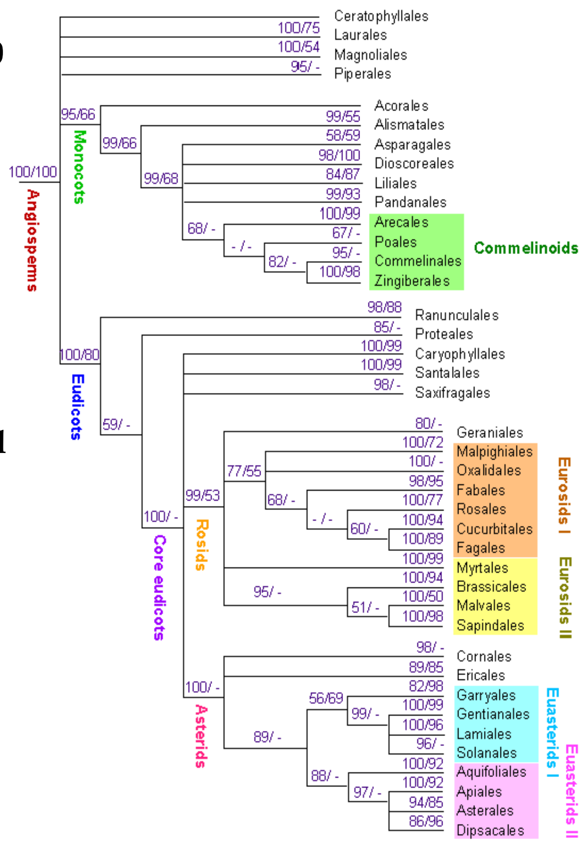
Salient features of APGC

- **The system is based on the sound phylogenetic principle of constructing taxa on the basis of established monophyly.**
- **The traditional division of angiosperms has been abandoned and various monocot taxa placed in between primitive angiosperms and eudicots.**
- **The monocots are placed under two groups, the commelinids and the rest of the monocot. These two groups find their place after primitive angiosperms.**

APG CLASSIFICATION

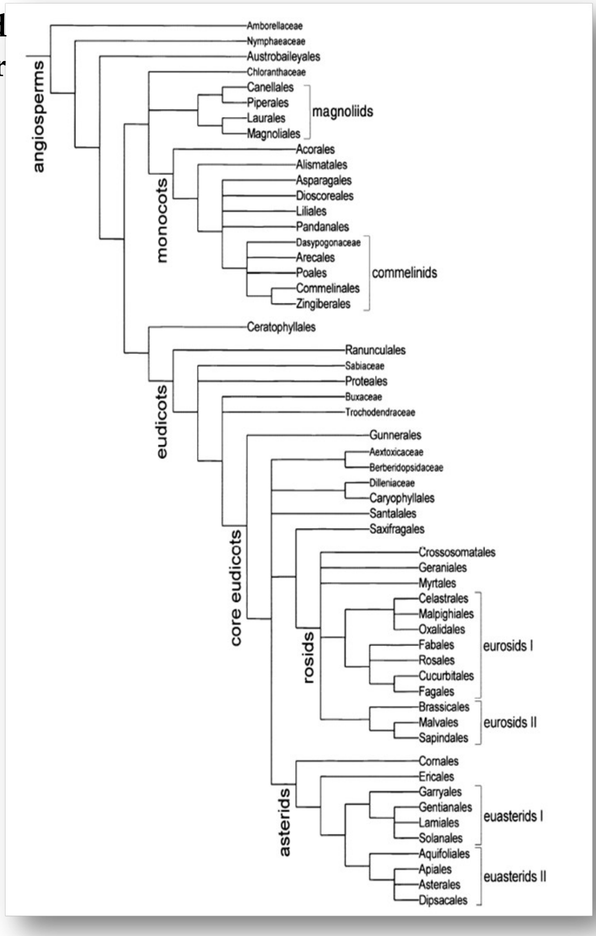
APG 1998

- APG 1998 recognized 462 families under 40 monophyletic orders which were classified under few informal monophyletic higher groups: monocots, eudicots, rosids, asterids etc.
- There are 81 unplaced families



APG II (2003)

- APG II recognized 457 families under 45 orders
- Of the 45 orders, 44 are placed in 11 informal groups.
- Contrary to APG 1998 which has 81 unplaced families, in APG II, this number has been reduced to 40.



APG 2003

APG III (2009)

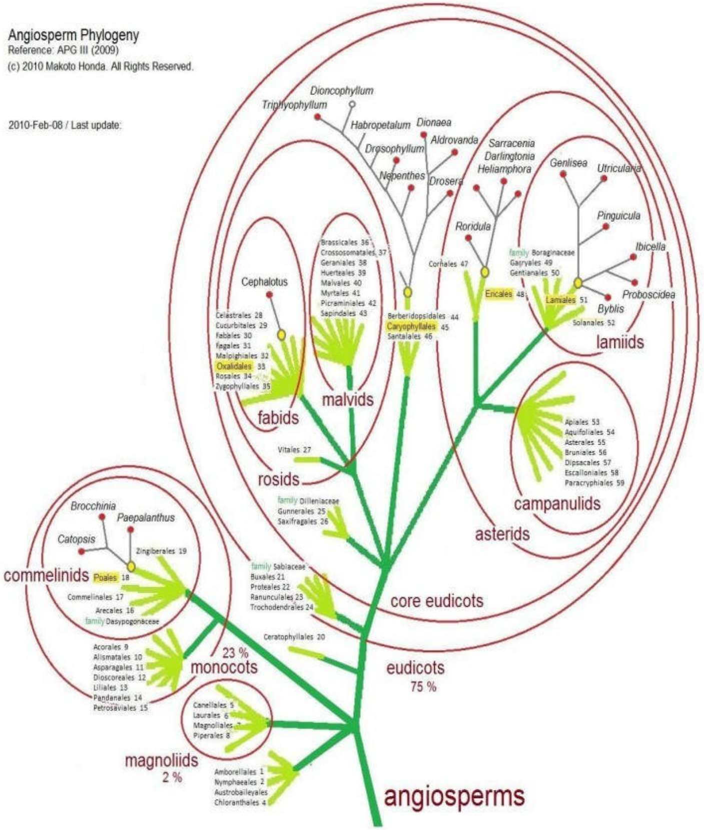
- **Published in October, 2009 by a team of 8 scientists in the name of APG III. Prof. P.F. Stevens led the revised edition**
- **Total 413 families.**
- **Except 10 families like Ceratophyllaceae, Boraginaceae, rest of the 403 families are assigned to 59 orders.**

- **11 clades**
- **59 orders (5 unplaced-not in clades)**

  (4 at beginning/ 1- after monocots- Ceratophyllaceae)
- **413 families**
- **Unplaced within the orders -10 families (e.g. Boraginaceae)**
- **Taxa of uncertain position**

  2 families: Apodanthaceae/ Cynomoriaceae

  3 genera : *Gumillea, Petenaea* and *Nicobariodendron*



APG IV (2016)

- Published on March 24, 2016
- 64 orders
- 416 families
- Unplaced one limited to 7 genera

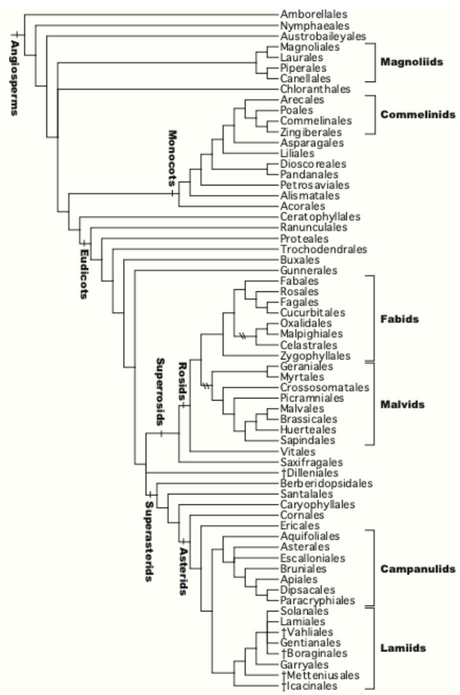


Figure 1. Interrelationships of the APG IV orders and some families supported by jackknife/bootstrap percentages >50 or Bayesian posterior probabilities >0.95 in large-scale analyses of angiosperms. See text for literature supporting these relationships. The alternative placements representing incongruence between nuclear/mitochondrial and plastid results for the Celastrales/Oxalidales/Malpighiales (COM) clade are indicated by slash marks (\\). †Orders newly recognized in APG.

BASAL ANGIOSPERMS

ANA GRADE- AMBORELLALES/ NYMPHAEALES/ AUSTROBAILEYALES

INDEPENDENT LINEAGE - CHLORANTHALES

MESANGIOSPERMS

1. MAGNOLIIDS - 4 ORDERS

2.MONOCOTS (11 ORDERS) - COMMELINIDS (4 OREDERS)- NOW MERGED

PROBABLE SISTER OF EUDICOTS-CERATOPHYLLALES

3. EUDICOTS (43 ORDERS)-4 ORDERS

4.CORE EUDICOTS (39 ORDERS)

ORDER 1- DILLENIALES

5.SUPERROSIDS (18 ORDERS)-

ORDER 1- SAXIFRAGALES

6. ROSIDS (17 ORDERS)

ORDER 1-VITALES

7. FABIDS-8 ORDERS

8. MALVIDS – 8 ORDERS

9. SUPERASTERIDS (20 ORDERS)-

ORDERS 3- BERBI/SANTA/CARYOPHY

10. ASTERIDS (17 ORDERS)-

ORDERS 2- ERICALES/ CORNALES

11. LAMIIDS- 8 ORDERS

12. CAMPANULIDS- 7 ORDERS

APG IV (2016)

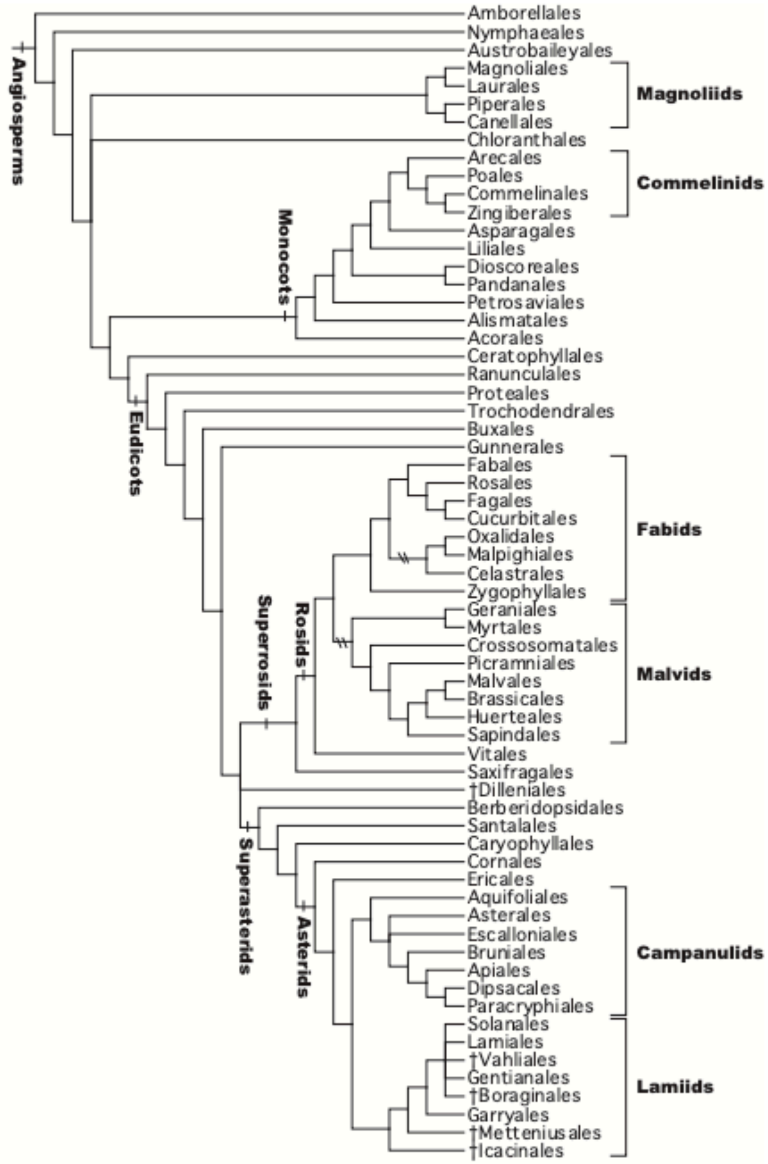


Figure 1. Interrelationships of the APG IV orders and some families supported by jackknife/bootstrap percentages >50 or Bayesian posterior probabilities >0.95 in large-scale analyses of angiosperms. See text for literature supporting these relationships. The alternative placements representing incongruence between nuclear/mitochondrial and plastid results for the Celastrales/Oxalidales/Malpighiales (COM) clade are indicated by slash marks (\\). †Orders newly recognized in APG.

Compared to the APG III system, the APG IV system recognizes five new orders (Boraginales, Dilleniales, Icacinales, Metteniusales and Vahliales), along with some new families, making a total of 64 angiosperm orders and 416 families.[1] In general, the authors describe their philosophy as "conservative", based on making changes from APG III only where "a well-supported need" has been demonstrated. This has sometimes resulted in placements that are not compatible with published studies, but where further research is needed before the classification can be changed.

APG IV (2016)

Family delimitations in APG

- Asclepiadaceae merged with Apocynaceae
- Bombacaceae, Sterculiaceae and Tiliaceae are merged with Malvaceae.
- Brassicaceae *s.l.* split into 3 families' viz., Brassicaceae *s.s.*, Capparaceae and Cleomaceae.
- Chenopodiaceae merged with Amaranthaceae
- Euphorbiaceae *s.l.* is split into Euphorbiaceae *s.s.*, Phyllanthaceae, Picrodendraceae and Putranjivaceae.
- Fabaceae comprises three subfamilies: Faboideae, Ceasalpinioideae and Mimosoideae.
- Liliaceae *s.l.* is split into 14 families and many taxa are transferred to Asparagaceae
- Molluginaceae and Gisekiaceae are recognized separately from Aizoaceae.

LARGEST FAMILIES

- **Orchidaceae (880/ 27,800)**
- **Asteraceae (1620/ 23,600)**
- **Fabaceae (745/ 19,560)**
- **Rubiaceae (611/ 13,150)**
- **Poaceae (707/ 11,337)**

Modern Classification of Angiospermae

- The APG (Angiosperm Phylogeny Group) II system is based on published cladistic analyses primarily utilizing molecular data or a combination of morphological and molecular data
- Recent studies have shown that the dicots are polyphyletic
- Some plants are actually ancient angiosperm lineages that are now collectively referred to as the basal angiosperms

  ☞ consists of several families, including:

  1. Amborellaceae
  2. Nymphaeaceae
  3. Illiciaceae

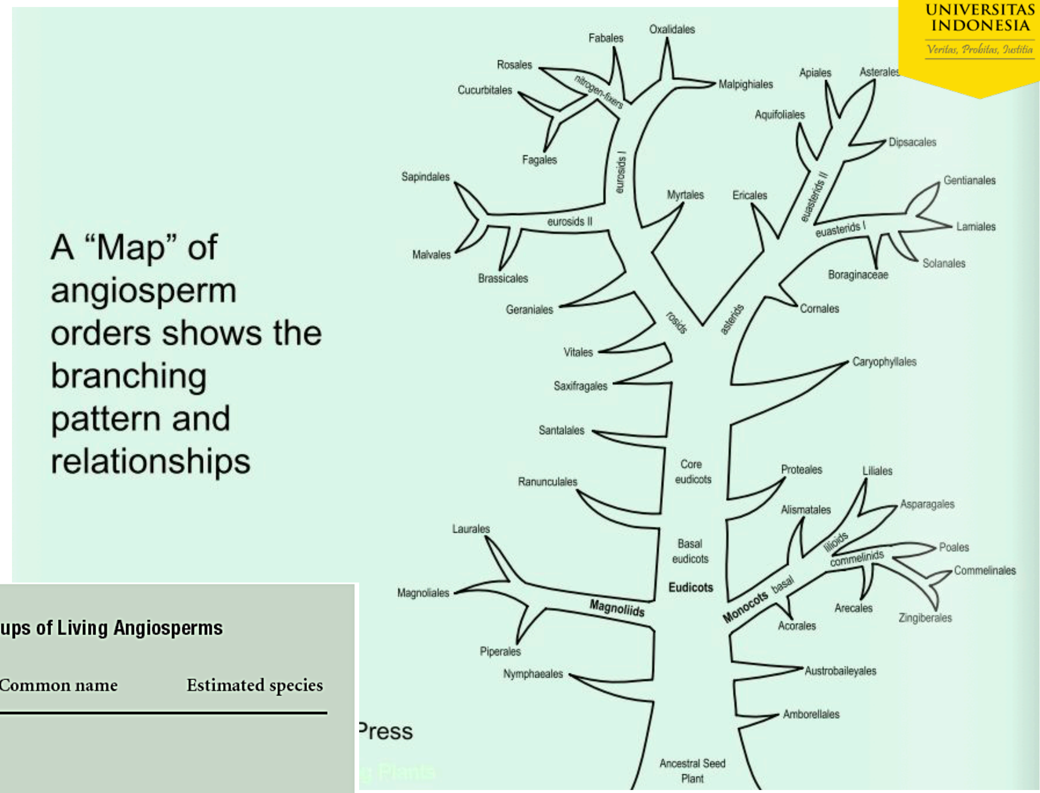


Table 7.1 Major Groups of Living Angiosperms

Group	Common name	Estimated species
Amborellaceae		
Nymphaeaceae		
Autrobaileyales	basal angiosperms	170
Nymphaeaceae, Illiciaceae		
Magnoliopsida*	magnoliids	9,000
Liliopsida	monocots	70,000–72,000
Magnoliopsida*	eudicots	175,000–180,000

* Magnoliopsida is the traditional name given to dicots. At present there is no ICBN name for the separate magnoliid or eudicot clades.

- The remaining angiosperms are now referred to as the core angiosperms
- This group includes three monophyletic lineages:

1. Magnoliids
2. Eudicots
3. Monocots

Modern Classification of Angiospermae

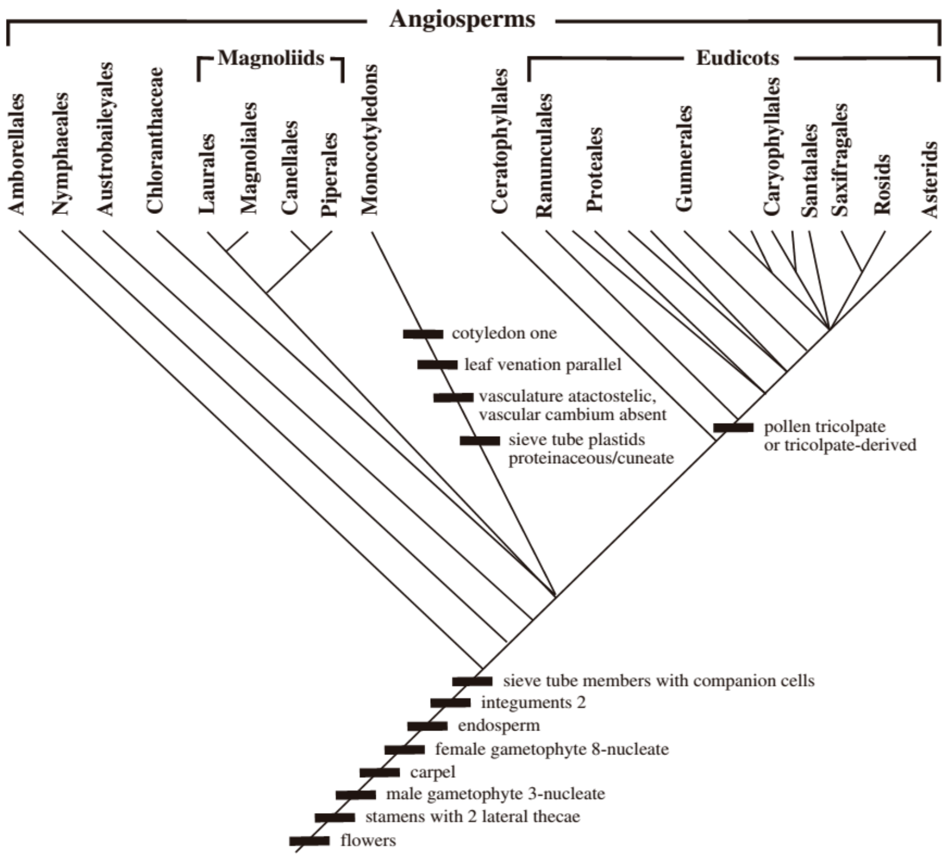


FIGURE 7.1 Phylogenetic relationships of major angiosperm clades, from APG II, 2003, with selected apomorphies shown (see Chapter 6).

Table 7.2 Differences Between the Three Core Angiosperm Groups

Trait	Monocots	Magnoliids	Eudicots
Cotyledons	1	2	2
Vascular bundle arrangement in stem	scattered	ring	ring
Leaf vein pattern	parallel	pinnate	palmate, pinnate
Number of flower parts	three-merous	many	four-merous, five-merous
Openings in pollen grains	1	1	3

Modern Classification of Angiospermae

TABLE 7.1 Major groups of the angiosperms, listing orders and included families (after APG III, 2009) for groups other than monocots (see Tables 7.2, 7.3) and eudicots (see Chapter 8). Families in **bold** are described in detail. An asterisk denotes a deviation from APG III, with brackets indicating the more inclusive family recommended by APG III.

ANGIOSPERMS

AMBORELLALES
- **Amborellaceae**

NYMPHAEALES
- **Cabombaceae**
- Hydatellaceae
- **Nymphaeaceae**

AUSTROBAILEYALES
- Austrobaileyaceae
- **Illiciaceae*** [Schisandraceae]
- Schisandraceae
- Trimeniaceae

CHLORANTHALES
- Chloranthaceae

MAGNOLIIDS

LAURALES
- Atherospermataceae
- Calycanthaceae
- Gomortegaceae
- Hernandiaceae
- **Lauraceae**
- Monimiaceae
- Siparunaceae

MAGNOLIALES
- **Annonaceae**
- Degeneriaceae
- Eupomatiaceae
- Himantandraceae
- **Magnoliaceae**
- Myristicaceae

MAGNOLIIDS (continued)

CANELLALES
- Canellaceae
- Winteraceae

PIPERALES
- **Aristolochiaceae** (incl. Lactoridaceae)
- Hydnoraceae
- **Piperaceae**
- **Saururaceae**

MONOCOTS (see Table 7.2, p. 204; Table 7.3, p. 231)

CERATOPHYLLALES
- **Ceratophyllaceae**

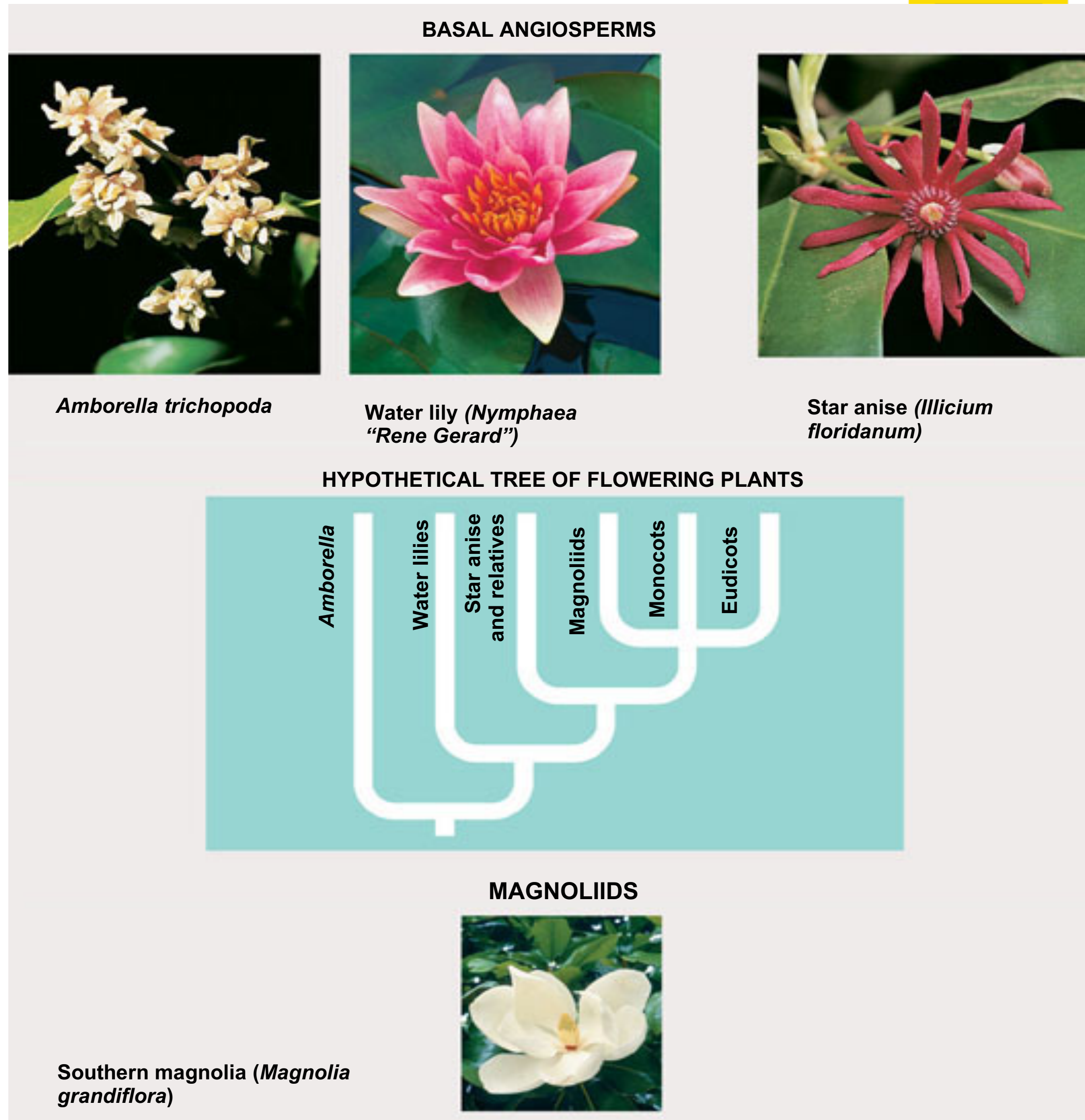
EUDICOTS (see Chapter 8)

Basal angiosperm

- Amboralales → One family and one species
- The absence of vessels in the order, which is rare in angiosperms, is possibly an ancestral condition, and the absence of aromatic (ethereal) oil cells is significant in light of other basal groups that have them.

Amborellaceae → one genus and one species

- *Amborella trichopoda* , shrub found only on New Caledonia



Other early branches include water lilies & the star anise
& relatives
- star anise family has female gametophyte w. only
4 nuclei, some spp. used as spices and medicines

Magnoliids are more speciose (~8,000 spp.), including magnolias, laurels, & black pepper plant

Monocot & Dicot

- In 1703, English botanist John Ray divided angiosperms into monocots and dicots
- Botanists have traditionally followed this classification and continued to divide angiosperms into the Magnoliopsida (dicots) and Liliopsida (monocots) based on a variety of traits, such as:

1. the arrangement of vascular bundles
2. features of roots, leaves, and flowers

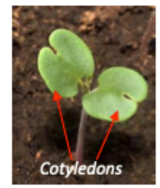
If you want to dig a little, dicots have a taproot system, with one large root at the base of the plant and smaller roots that branch out from it as shown on the plants pictured to the left. The taproot was the first root that emerged from the seed, which is known as the radicle. Monocots have a root system that is composed of a network of fibrous roots as shown in the picture to the right. These roots all arose from the stem of the plant and are called adventitious roots.

Also, woody trees that are not gymnosperms (pine, cedar, cypress, etc.) are dicots. Their stems have a layer of actively growing cells between the bark and the wood known as the cambium that allows the stem to grow laterally and increase trunk diameter. This is what creates the annual growth rings in the wood as shown in the in the cross-section of a tree trunk pictured to the left. You don't have to cut the tree down to see growth rings, because there is cambium in the branches as well that also allows them to grow in diameter. Some monocots, like palms, may have hardened stems, but their trunks do not have a cambium layer and are not capable of outward stem growth like woody dicots. As you can see in the picture to the right, there are no annual growth rings in the cross-section of palm trunk.

There are other features that can distinguish a monocot from a dicot, however, these are generally only visible at the microscopic level. If you wish to find out what these anatomical differences are, type in monocot vs. dicot in any search engine and you will find multiple references that provide these details.

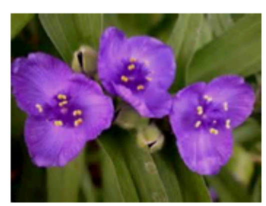
Dicot or Monocot? How to Tell the Difference

Flowering plants are divided into two groups - monocots and dicots. Recognizing which of these two groups a plant belongs to is a great time saver when you are out in the field trying to identify a plant using a key. The names or these groups are derived from the number of cotyledons or seed leaves that the embryonic seedling has within its seed. A monocot, which an abbreviation for monocotyledon, will have only one cotyledon and a dicot, or dicotyledon, will have two cotyledons. However, this distinction will not help you when you are trying to determine which group a plant belongs to if it is no longer a seedling. And, sometimes doesn't even help if you are looking at a seedling, because many plants do not bring their cotyledon(s) above the soil surface when they germinate as the seedling shown to the left did.

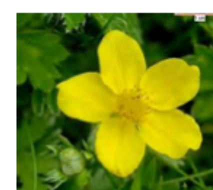


Here are some key features to look for to determine whether a plant is a monocot or a dicot.

Leaves of dicots have veins that are branched. Sometimes the veins branch out on either side of the leaf from a middle vein, in an arrangement resembling a feather (pinnate arrangement) shown in the picture below left. Other dicots have veins that branch out from a single vein, like fingers on a hand (palmate arrangement) shown in the picture to the right. Monocots have veins that are parallel to one another as shown in the picture below right. However, this does not mean that all monocots have narrow grass-like leaves. Arrowhead (left) is a monocot. Because the leaves have lobes that hang downwards, it almost looks like the veins branch out in the same manner as described for palmate veins. However, if you look closely, you can see that all the veins originate at the base of the leaf and are parallel to each other in each lobe of the leaf.



If your plant is flowering, you can tell if it is a monocot or dicot by the number of petals and other flower parts. Monocots have flower parts in threes or multiples of threes as shown in the flowers to the left. Dicots have flower parts in multiples of fours or fives like the five-petaled dicot flower pictured to the right.



The 2 big groups of angiosperms are the **Monocots** (~70,000 spp.) & the **Eudicots** (~ 170,000? spp.)

Monocots include orchids, palms, lilies, grasses…

Dicots include… lots! (oaks, peas, roses, potatoes, etc.)

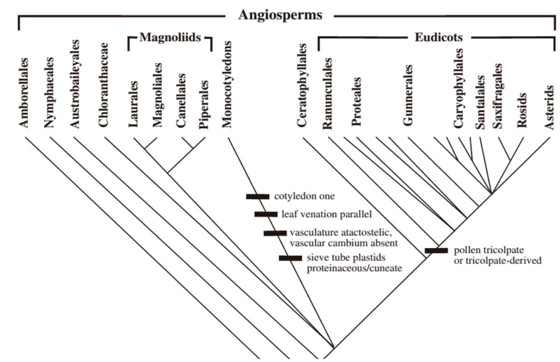
Eudicots

The true dicots = **eudicots** all have 3-pored pollen

They are the largest group of angiosperms, and are quite diverse

The main groups include:

Ranunculids Caryophyllids Rosids Asterids



- The eudicots are a large, monophyletic assemblage of angiosperms, comprising roughly 190,000 described species, or 75% of all angiosperms.
- The monophyly of eudicots is well supported from molecular data and delimited by at least one palynological apomorphy: a tricolpate or tricolpate derived pollen grain
- Many eudicots have pollen grains with more than three apertures, of a great variety of numbers, shapes, and position

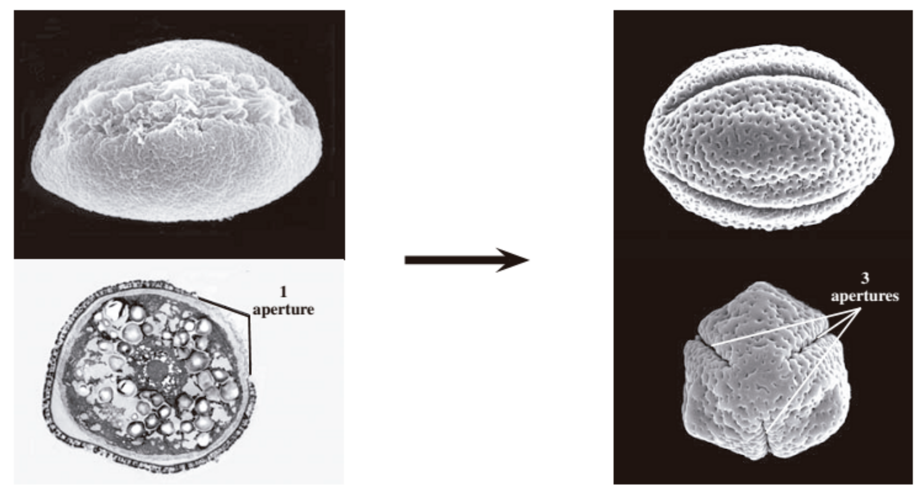


FIGURE 8.2 Transformation from monosulcate to tricolpate pollen grain, the latter an apomorphy of the Eudicots.

Four evolutionary trends among flowers

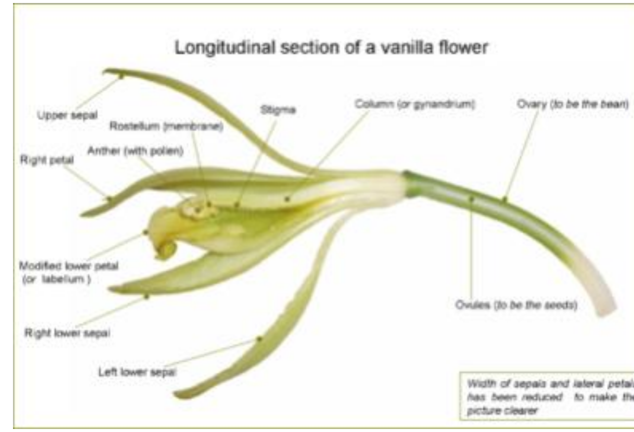
1. floral parts many -> few
2. floral whorls from 4, long floral axis, separate parts -> reduced whorls, short floral axis, fused parts
3. superior -> inferior ovary
4. symmetry radial -> bilateral

Figure 20-8b
Biology of Plants, Seventh Edition

Nelumbo (Lotus)

Figure 20-8c
Biology of Plants, Seventh Edition

Lonicera (honeysuckle)



Vanilla (vanilla bean orchid)

1. floral parts few
2. reduced whorls, short floral axis, fused parts
3. inferior ovary
4. bilateral symmetry

Figure 20-11a
Biology of Plants, Seventh Edition

Anemone

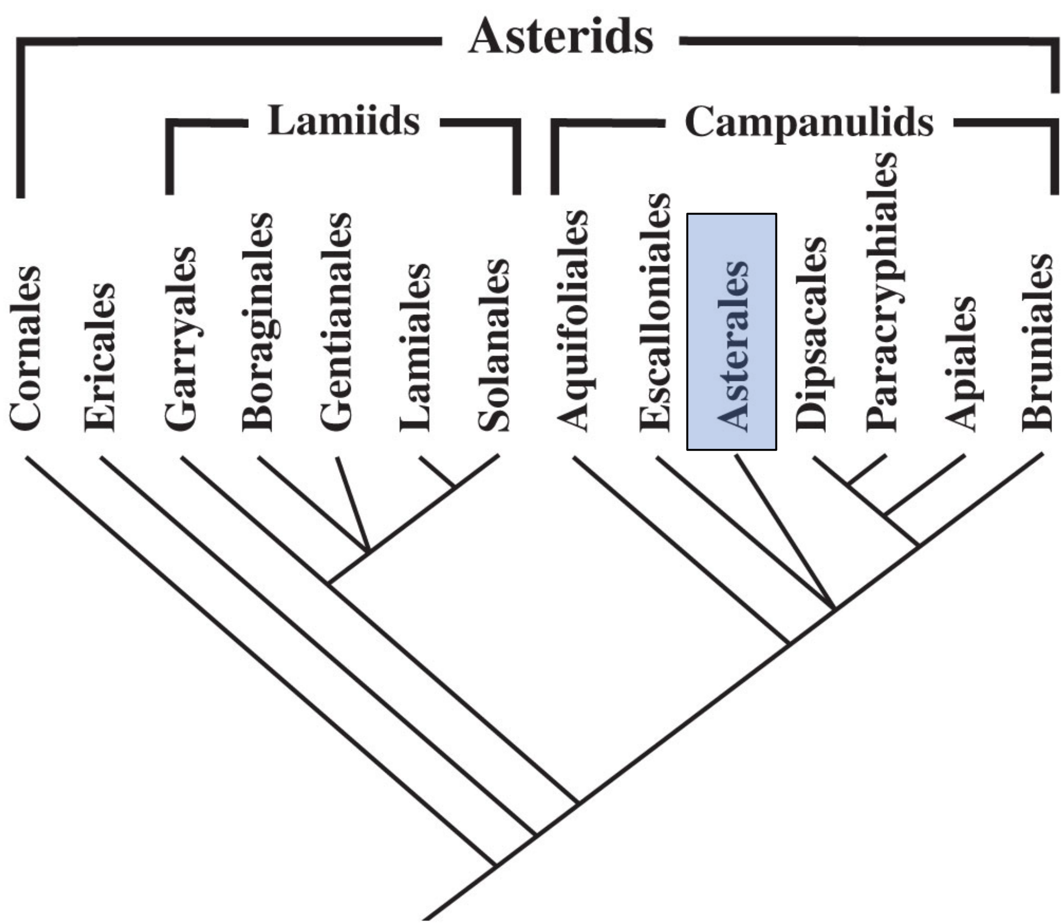
Helianthus
disk floret

Order Asterales

Asteraceae (=Compositae)

Sunflower Family
1620 genera
23,600 species

1) most diverse dicot family
2) 98% herbaceous, but shrubs, trees or vines also
3) inflorescence a head, subtended by involucre of phyllaries
4) K 0-∞ C (5) [4] or (3) A (5) [(4)] G (2) inferior

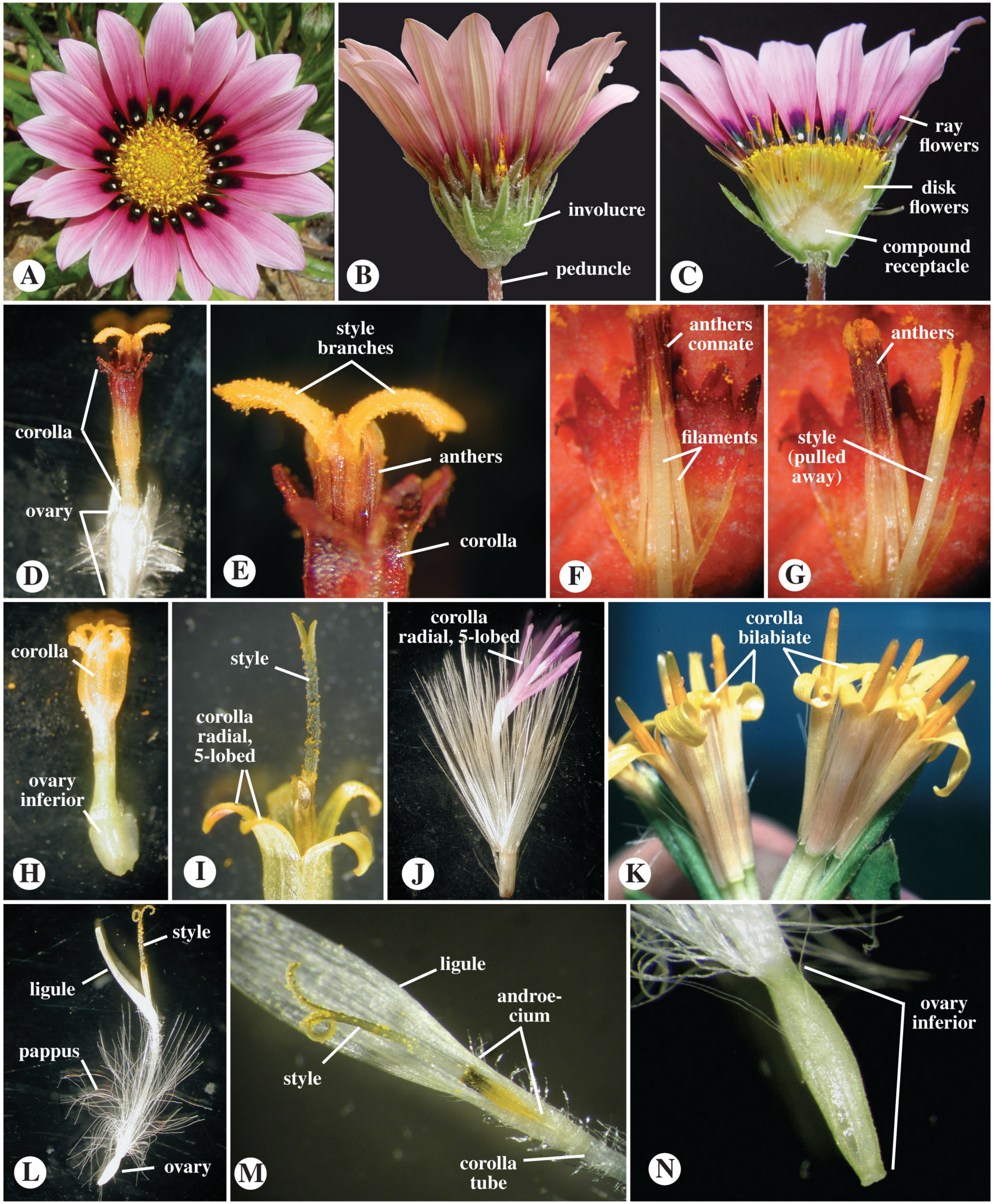


p. 429
Fig. 8.131

Order Asterales

Asteraceae (=Compositae)

Sunflower Family
1620 genera
23,600 species



p. 430
Fig. 8.132

Order Asterales

Asteraceae (=Compositae)

Sunflower Family
1620 genera
23,600 species

p. 431
Fig. 8.133

Order Asterales

Asteraceae (=Compositae)

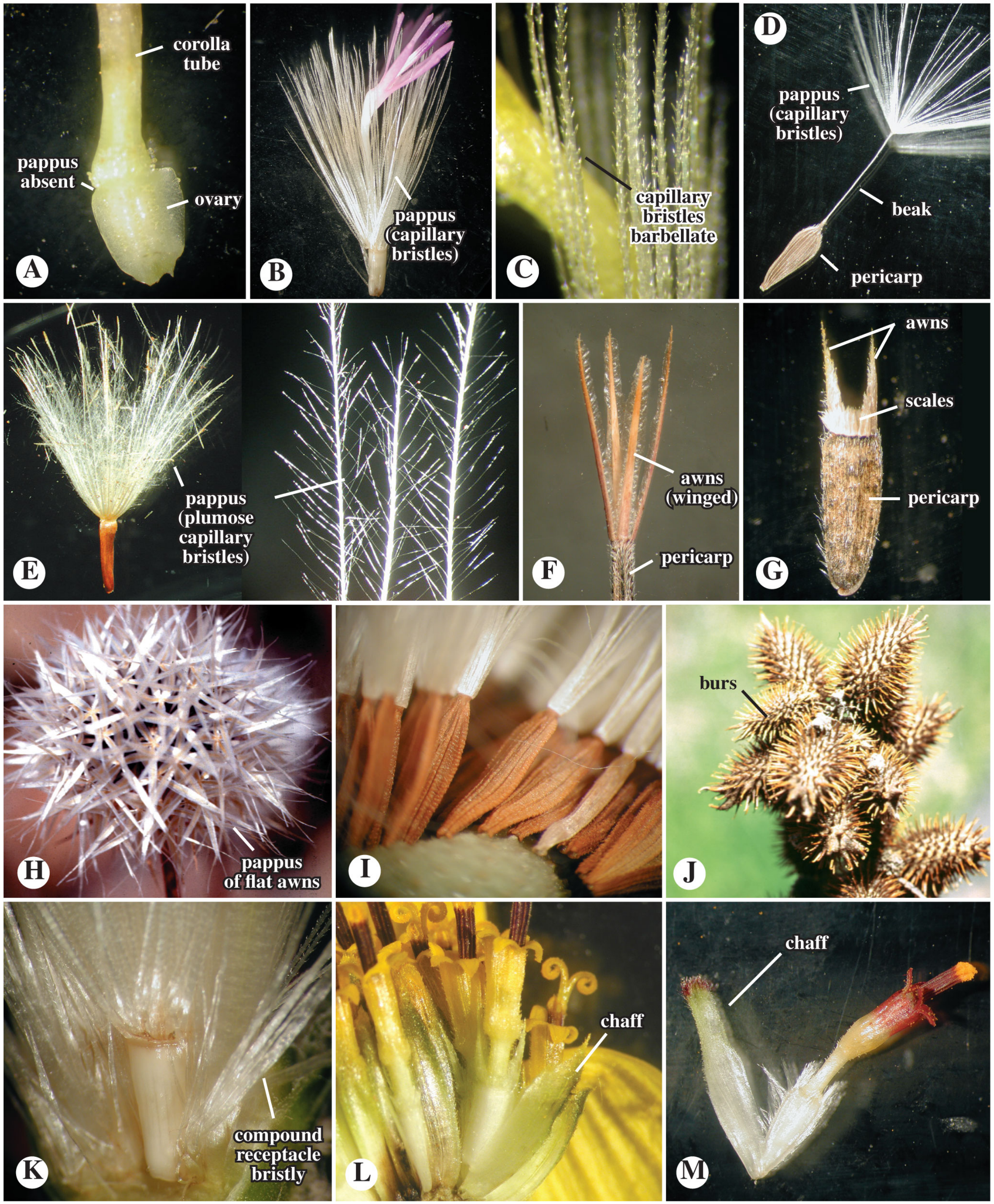
Sunflower Family
1620 genera
23,600 species

p. 432
Fig. 8.132

Order Asterales

Asteraceae (=Compositae)

Sunflower Family
1620 genera
23,600 species



Monocotyledons: monocots, Monocotyledoneae, or Liliopsida

- Chapter 7
- Simpson, 2nd Edition

REFERENCES

- Simpson, M.G. 2010. Plant systematics. 2nd ed. Elsevier Academic Press. New York: 754 hal
- https://www.digitalatlasofancientlife.org/learn/embryophytes/angiosperms/angiosperm-phylogeny/
- APG: https://slideplayer.com/slide/13508466/
- Dikot and monocot: https://www.nrcs.usda.gov/Internet/FSE_PLANTMATERIALS/publications/flpmctn12686.pdf
- https://www.yumpu.com/en/document/read/12045948/pdf-a-tour-of-the-flowering-plants-colorado-native-plant-society
- http://sytsma.botany.wisc.edu/fieldbotany/ppt/Angiosperms.pdf
- https://www.slideshare.net/DrRaviPrasadRaoBoyin/angiosperm-classifications