FLOWERING PLANTS: THE ANGIOSPERMS

This laboratory will serve to introduce you to the subject of the morphology of the flowers of angiosperms, the flowering plants, and features of their life cycle. The range of flora structure present among the angiosperms is staggering. In general, each family has a distinct floral type, and most genera are also fairly distinct in their floral structure. Numerous modifications of the basic parts of the flower are present in various plants. These modifications occur in combination with fusion of parts, various forms of parts, and reduction of parts, producing almost limitless variation in floral morphology.

Although classically angiosperms were divided into dicots (having embryos with two cotyledons) and monocots (having embryos with one cotyledon), we now recognize that the dicots are a paraphyletic group with the monocots nested within them. Thus, the dicotyledonous embryo is a symplesiomorphy (shared ancestral character), whereas the monocotyledonous embryo is a synapomorphy (shared derived character) for the monocots (Doyle 2013). Regardless, the majority of angiosperm diversity is in two major clades: the monocots and the eudicots. Below is a very simplified outline of the classification of angiosperms condensed primarily from the Angiosperm Phylogeny Group classification (APG III 2009) and the Angiosperm Phylogeny Website (Stevens 2001-present); these sources also discuss some uncertainties regarding the overall phylogeny of the angiosperms. Fig. 20-7 in Raven 8th ed. (pg. 482) shows a simplified summary tree of angiosperm relationships.

1. **Amborella tricopoda** (Amborellales), New Caledonia. The most basally-diverging angiosperm species and sister to the remaining living angiosperms.
2. **Nymphaeales**: Water lilies and relatives, 3 families.
3. **Austrobaileyales**: 3 families.
4. Chloranthaceae + Magnoliids clade:
   a. **Chloranthaceae** (Chloranthales): possible sister group to Magnoliids.
   b. **Magnoliids**: 4 orders (Canellales, Laurales, Magnoliales, and Piperales). Some members of this group—such as *Asarum canadense* (wild ginger), *Asimina triloba* (pawpaw), *Liriodendron tulipifera* (tulip poplar or tuliptree), and *Magnolia*—may be familiar to you from the Athens area.
5. **Monocots**: This large clade is characterized by having one cotyledon in the embryo, as well as other distinctive features. The most basally-diverging monocot is *Acorus* (sweet-flag), which is widespread in the northern hemisphere. Some large or notable groups include the bromeliads (the group that pineapple is in), grasses, irises, lilies, orchids, and palms. The largest family of monocots is the Orchidaceae, or orchid family (*The Plant List* 2013). Although estimates of its species diversity vary, this family likely includes more than 20,000 species.
6. **Ceratophyllum** + eudicots clade:
   a. **Ceratophyllum** (Ceratophyllales): This genus of aquatic plants, commonly known as hornwort, is distributed worldwide. It is considered sister to the eudicot clade.
   b. **Eudicots**: The most decisive synapomorphy for this group is tricolpate pollen, or pollen with three elongate apertures (Doyle 2013). There are two major clades of eudicots: the rosids and the asterids, as well as a number of other groups that occur outside of these clades. Most angiosperm diversity is in this group and providing a complete survey is beyond the scope of this course. By number of species, the largest eudicot families are the asterid family Asteraceae (the aster/sunflower family) and the rosid family Fabaceae (the legume family) (*The Plant List* 2013). Estimates vary, but each family has around 20,000+ species.

In the first portion of the laboratory you will study typical eudicot and monocot flowers to refresh your knowledge of the basic floral parts and associated terminology. The second portion of the laboratory will deal with the range of floral structure. This latter part is designed to let you attempt to interpret the flora structures and to appreciate some of the major variations in flower type. (You will not be held responsible for the specific names of the examples.)

**STRUCTURE OF TYPICAL EUDICOT & MONOCOT FLOWERS**

**General structure**

If necessary, review the parts of the flower and the identity of the four floral whorls found in a **complete** flower. You can use *Raven* 8th ed. pgs. 460-463, or any other standard botany text, for guidance.

Obtain a typical eudicot flower and note the nature, number, and arrangement of the parts (sepals, petals, stamens, and pistil or pistils). Note the anther and narrow filament of the stamens, and the stigma(s), style(s), and ovary of the pistil(s). What do the terms **corolla** and **calyx** refer to? What is the **perianth**?

Carefully cut a median longitudinal section of the flower. Note the level at which the parts are borne upon the **receptacle**. Sketch the eudicot flower as it appears in longitudinal section and label the parts.

Carefully cut a transverse section of the ovary and locate the ovary wall, vascular supplies, locule(s), and ovule(s). Does the ovary appear to be simple (a simple ovary is made up of one carpel) or compound (a compound ovary made up of more than one carpel, with the carpels fused)? The term **placenta** is used to denote the region(s) where the ovules are attached to the ovary wall. Locate the placenta(s). Diagram the transverse section of this eudicot ovary.

Repeat the process of examination and dissection for a typical monocot flower. Be sure to sketch the monocot flower in longitudinal section and diagram the ovary in transverse section.
Once you have finished both dissections, compare the results. Are the numbers of parts in each floral whorl different in the eudicot and monocot flowers? Are the petals and sepals morphologically distinct in each type of flower, or not?

**Position of the ovary**

The position of the ovary with respect to the other floral parts varies greatly in flowers. The **superior** condition is one in which the ovary lies above the level of insertion of the perianth and stamens of the flower on the receptacle. If the perianth parts and stamens are attached below the ovary, the flower is called **hypogynous**. If the perianth parts and stamens appear to arise on the rim of a floral cup (hypanthium) that surrounds the ovary but is not fused to the ovary wall, the flower can be said to be **perigynous**.

The opposite extreme to the superior ovary is the **inferior** ovary, which lies below the level of insertion of the other floral parts. A flower with an inferior ovary can be said to be **epigynous**. Flowers can have ovaries that are partially inferior (i.e., intermediate between fully superior and fully inferior) where the perianth and stamens appear to be inserted on the ovary wall.

Which of these conditions (i.e., epigynous flower with inferior ovary, hypogynous flower with superior ovary, perigynous flower with superior ovary, flower with partially inferior ovary) were present in the flowers you just finished dissecting? Examples of flowers with different ovary positions and insertion of parts are present in the laboratory. Find and sketch at least one example of each condition.

**Morphological Variation & Floral Evolution**

Examine the selection of flowers in the laboratory. These illustrate numerous features of floral structure.

**Summary of floral evolutionary trends**

The following trends are believed to have occurred numerous times during the course of evolution of the flowering plants. Try to find at least one flower that exemplifies both the ancestral (“primitive”) and derived (“advanced”) state in each of the listed trends. If you wish, you may use an arbitrary scoring system to gain some idea of the relative degree of advancement shown by the various flowers in the laboratory.

Ancestral → Derived

1. Numerous parts, indefinite number → few parts, definite number
2. Several free, simple pistils → compound pistil
3. Spiral arrangement of parts on floral axis → whorled arrangement of parts on floral axis
4. Leaf-like perianth parts → modified perianth parts (not obviously leaf-like)
5. Radial symmetry (actinomorphic/regular flowers) → bilateral symmetry (zygomorphic/irregular flowers)
6. Superior ovary → inferior ovary
7. Bisexual flowers → unisexual flowers
8. Flowers complete → flowers lacking calyx and corolla
9. Individual flowers clearly recognizable → groupings of several flowers, organized into tight clusters which themselves resemble flowers

**Pollination**

Flowers often display groups of floral characteristics that are associated with a particular type of pollinator. *Raven, 8*th ed., covers some of these (pgs. 487-490). As you examine the various flowers, note their characteristics and speculate on the type of pollinator that might be attracted to a given flower. Below are some characteristics to consider:

- **Wind-pollinated**: reduced size, lack of brilliant color, lack of odor, reduced accessory organs, prominent/exposed anthers and stigma.
- **Animal-pollinated**: size; odor (present or absent, good or bad-smelling); color and color patterns (e.g., bright, white/light-colored, dull and mottled, etc.); placement of parts to facilitate pollen transfer; reward for pollinator (e.g., pollen, nectar, none).

How do you think that coevolution with pollinators has influenced the trends in floral characteristics listed in the previous section?

**INTERNAL ANATOMY OF THE FLOWER**

**Hypogynous-type: Capsella (shepherd’s purse)**

Examine a prepared slide of *Capsella* (eudicots, rosids, Brassicaceae or Cruciferae = the mustard family). This slide is cut through an entire inflorescence, and flowers may be found in varying stages of development. As is typical of Brassicaceae, the mature flower has four sepals, four petals, six stamens, and a compound pistil of two carpels. The flower is hypogynous, and the ovary has two locules with numerous ovules.

**Epigynous-type: Erigeron (fleabane)**

Examine a prepared slide of a flower with an inferior ovary (e.g., an epigynous flower) such as *Erigeron* (eudicots, asterids, Asteraceae or Compositae = the aster family). Note the differences between these flowers and the hypogynous flower that you examined. *Pay special attention to where the perianth parts and stamens appear to emerge on the flower.*

**Perigynous-type: Prunus (cherry, plum, etc.)**

Examine a prepared slide of the flower of *Prunus* (eudicots, rosids, Rosaceae = the rose family) on demonstration. This is a perigynous flower with a superior ovary. Note the single
pistil and the hypanthium surrounding it. Note the position where the free parts of the perianth and stamens arise in the flower.

REPRODUCTION OF THE FLOWERING PLANTS

In this portion of the laboratory, we will deal with cytological aspects of the reproduction of a typical flowering plant. Emphasis will be placed on the events occurring within the anthers and ovules, including the development of the micro- and megagametophytes.

Traditionally, the genus *Lilium* (monocots, Liliaceae = the lily family) has been used to represent the typical flowering plant reproductive cycle. The structures are large, and the material is easily obtained. It was discovered, however, that *Lilium* differs from the vast majority of flowering plants. The atypical nature of the genus lies primarily in the mode of development of its megagametophyte, which is not of the usual or Polygonum-type. *Lilium* instead has the Fritilliaria-type of embryo sac development. (Refer to your textbook to note how this differs from the Polygonum-type.)

Megaspore mother cell and megagametophyte development

For this section we will use a series of four *Lilium* slides. First, examine the megasporocyte slide and note the general organization of the ovary as it appears in transverse section. Locate the ovary wall, locules, ovules, and the nucellus and integument of the ovules. Find the relatively massive megaspore mother cell (= megasporocyte).

Next, examine the 2-nucleate and 4-nucleate stages of embryo sac development. What types of changes are occurring during development?

Finally, examine the 8-nucleate stage. This is the mature embryo sac or megagametophyte. You should be able to locate: three antipodal cells near the end of the embryo sac farthest from the micropyle; three cells near the micropylar end of the embryo sac, which are the single egg cell and two synergids; and two free nuclei near the center of the embryo sac, which are the polar nuclei. Examine several sections in sequence if necessary to see all of these features.

After examining the series of *Lilium* slides, make a series of drawings of the embryo sac development. Draw the entire ovule in addition to the sac for the mature 8-nucleate stage.

Microspore mother cell and microgametophyte development

Obtain a prepared slide of young *Lilium* anthers having microspore mother cells (= microsporocytes). Note the appearance of the mother cells and the surrounding tapetal tissue. Also obtain a slide of a later stage of development of the microspores and a slide showing the tetrads of microspores within the pollen sac.
Examine a slide of mature *Lilium* anthers. *Lilium* has very obvious areas on either side of the anther where the sacs open. Prior to the release of the pollen, the wall between each pair of pollen sacs on either side of the connective breaks down so that two cavities result. Each of these opens, releasing the pollen grains.

Attempt to find mature pollen grains in the above slide. They will be binucleate; the elongate nucleus is the generative nucleus; the more spherical one is the tube nucleus. Draw several stages in the production of microspore and the development of mature pollen grains.

**Fertilization**

Examine a demonstration slide illustrating double fertilization. The male gamete nuclei are recognizable by their elongate and curved shape. What results from this double fusion of nuclei? How does the endosperm of flowering plants differ from the tissue that nourishes the embryo in gymnosperms?

**EMBRYOGENY, SEEDS, & GERMINATION**

**Monocots**

**Early embryology: *Lilium* (lily)**

Examine a prepared slide of a transverse section of the ovary of *Lilium*. You will see the three locules and six rows of ovules. Within the nucellar region of the ovules, you will be see early stages in the development of the embryo and endosperm. The embryo will appear as a small cluster of cells near the micropylar end of the old embryo sac, while the endosperm will consist of scattered, relatively large nuclei lying in a common cytoplasm in the embryo sac. Note that most of the endosperm nuclei are near the margin of the sac. Draw the early stage of embryo and endosperm development.

**Mature seed: *Zea* (corn)**

Examine a mature kernel of *Zea* (monocots, Poaceae = the grass family) that has been soaked in water for one day. As in all grasses, the **grain** or **kernel** is actually a fruit whose outer portion is dry, hard ovary wall, or **pericarp**. This is fused with the outer part of the seed proper. You can locate the embryo as a light area (elliptical in outline) on one side of the kernel. Note the fused fruit-seed tissue, the massive endosperm (which is white), and the embryo. Examine the embryo. Note the two growing points and the somewhat slipper-shaped single cotyledon.

Examine a prepared slide of a median longitudinal section of the kernel of *Zea*. Locate the fruit-seed coat area, the endosperm, the embryo with two growing points, and the single massive cotyledon. You will find that the growing points are surrounded by sheaths of tissue: the **coleoptile**, covering the **epicotyl** or shoot apex; and the **coleorhiza**, covering the young primary root. Columnar digestive gland cells may be found lining the cotyledon. What is their function? Draw the median longitudinal section of the kernel.
Early development of young seedling: Zea (corn)

Examine germinating corn kernels. Note the appearance of the early seedling stages. What function does the cotyledon appear to serve? Does it appear above ground?

You will find numerous adventitious roots on the young seedling, as well as the primary root. The mature root system is of the diffuse (fibrous) type. You will also see the first foliage leaves breaking through the tip of the coleoptile. Sketch the seedling.

Eudicots

Embryology: Capsella (shepherd’s purse)

Examine a prepared slide of the genus Capsella (rosids, Brassicaceae or Cruciferae = the mustard family). Note that the slide bears the developing fruits of several flowers, each of which contains several developing seeds. Within the latter you will find various stages in embryo and endosperm development. You should find stages in which the embryo is pear-shaped and borne on a single row of cells. This row is the suspensor. Free nuclei of the endosperm will also be present.

As the embryo develops, its size increases, the cotyledons become much more prominent, and a shoot apex develops between the bases of the two cotyledons. Also, the lower portion of the embryo becomes an elongate hypocotyl, at whose lower tip the primary root will develop from a growing point (the radicle).

Slides of older fruits are also available, in which the mature seeds are present. Note that the integument tissue has developed into a seed coat; the walls of its cells are variously thickened and sclerotic. You may be able to locate a thin layer of darkly staining material near one of the cotyledons, appressed to the inner surface of the nucellus. This represents horny tissue developed from the antipodals. Endosperm is absent in the mature seed, having been broken down and reabsorbed by the embryo during the course of development. Diagram one or more of the stages in seed development in Capsella.

Seed structure: Pisum (pea) and Phaseolus (bean)

Examine soaked seeds of typical eudicots such as Pisum and Phaseolus (rosids, Fabaceae = the legume family) that lack endosperm. Remove the seed coat, which will come away with the nucellus adhering to its inner surface. Note the two large cotyledons making up the major portion of the embryo. Note also the hypocotyl and epicotyl, which are small and may be exposed by pulling apart the cotyledons. The primary root will develop from the lower tip of the hypocotyl region, the radicle. Note that the first foliage leaves are already present in the epicotyl region. Draw the embryo, indicating its parts, for one of the above seeds.

Also examine germinating seeds of the bean and pea. Note the difference in mode of germination, especially with respect to the cotyledons (location, color, etc.). What functions do the cotyledons appear to be carrying out in these two forms?
Draw the external features of one of the above seed types, noting the small micropyle in the seed coats and the point of attachment to the ovary wall, which may be found by locating a scar on the seed coat (the hilum).

REFERENCES


