Learning unit 4: Plant diversity II: the evolution of seed plants

4.1 Introduction

To complete the learning unit, you will need to refer to pages 692–709 chapter 30 in Campbell et al. (2015)

This learning unit will mainly focus on plants that reproduce by means of spores, haploid cells that disperse and germinate to produce gametophytes. Although gymnosperms and angiosperms also produce spores, their primary means of reproduction and dispersal is by seeds. Fossils and comparative studies of living plants offer clues about the origin of seed plants some 360 million years ago. As this new group became established, they dramatically altered the course of plant evolution. Indeed, seed plants have become dominant producers on land, and they make up majority of plant biodiversity today.

In this learning unit, we will first present the general features of seed plants—both gymnosperms and angiosperms. Then we will look at their evolutionary history and enormous impact on human society.

4.2 Learning outcomes

By the end of this learning unit you should be able to

• give an overview of the three variations of gametophyte/sporophyte relationships

• define the term seed and discuss the structure of a seed

• describe the life cycle of gymnosperms, clearly distinguishing between the gametophyte and sporophyte generations

• discuss the structure and function of flowers and fruits, as well as their reproductive adaptations

• describe the life cycle of angiosperms, clearly distinguishing between the gametophyte and sporophyte generations

4.3 Seeds and pollen grains are key adaptations for life on land

Recommended reading: pages 693–695 of chapter 30 in Campbell et al. (2015)

Three life cycle modifications led to the success of terrestrial plants:

<u>Reduction of the gametophyte</u>: retained in the moist reproductive tissue of the sporophyte.

<u>Origin of the seed</u>: zygotes developed into embryos packaged with a food supply within a protected seed coat. Seeds replaced spores as the main means of dispersal.

<u>Evolution of pollen</u>: plants were no longer tied to water for fertilisation.

Both mosses and ferns require water for Fertilisation. However, the presence of vascular (water-conducting) tissue in ferns has allowed the sporophyte to become independent of the gametophyte, to grow taller, and to exploit drier habitats.

Relatively harsh terrestrial environment: bryophytes and seedless vascular plants release spores. Seeds are hardier because of their multicellular nature. Seed is defined as a reproductive structure consisting of an embryo enclosed in its food supply and protected with a seed coat (integument). Seed is a sporophyte embryo and a food supply surrounded by a protective coat. All seed plants are heterosporous. Development of seed associated with megasporangia: seed plant megasporangia are fleshy structure called nucelli. Additional tissues (integuments) surround megasporangium. Resulting structure is called an ovule. Female gametophyte develops in wall of megaspore, is fertilised (embryo) and resulting ovule develops into a seed.

Advantages of seed:

- Seed with food supply can remain dormant a long time until favourable conditions warrants germination.
- Seed is dispersal unit
- Male gametophyte (=microgametophyte) of seed plants
- Develops within microspore
- Microspore of seed plants develops into pollen grain (male gametophyte)

Microspores develop into pollen grains which mature to form the male gametophytes of seed plants. Pollen grains coated with a resistant polymer, sporopollenin, and can be carried away by wind or animals (e.g. bees) following release from microsporangia. A pollen grain near an ovule will extend a tube and discharge sperm cells into the female gametophyte within the ovule. In some gymnosperms, sperm are flagellated (ancestral). Other gymnosperms (including conifers) and angiosperms do not have flagellated sperm cells.

4.4 Gymnosperms

Recommended reading: pages 695–699 of chapter 30 in Campbell et al. (2015)

The ovules and seeds of gymnosperms ("naked seeds") develop on the surfaces of modified leaves that usually form cones (*strobili*). In contrast, ovules and seeds of angiosperms develop in enclosed chambers called ovaries. The most familiar gymnosperms are the conifers, cone-bearing trees such as pine, fir, and redwood.

The four phyla of extant gymnosperms are Cycadophyta, Ginkgophyta, Gnetophyta, and Coniferophyta.

Phylum Ginkgophyta consists of only a single extant species, Ginkgo biloba. This popular ornamental species has fanlike leaves that turn gold before they fall off in the autumn. Landscapers usually plant only male trees because the coats of seeds produced by female plants produce a repulsive odour as they decay.

Cycads (phylum Cycadophyta) have large cones and palmlike leaves. 130 species of cycads survive today. Cycads flourished in the Mesozoic era, which was known as the "Age of Cycads." Phylum Gnetophyta consists of three very different genera. *Weltwitschia* plants, from deserts in southwestern Africa, have straplike leaves that are among the largest known leaves. *Gentum* species are tropical trees or vines. *Ephedra* (Mormon tea) is a shrub of the American deserts.

The conifers belong to the largest gymnosperm phylum, the phylum Coniferophyta. The term conifer comes from the reproductive structure, the cone, which is a cluster of scalelike sporophylls. Although there are only about 600 species of conifers, a few species dominate vast forested regions in the Northern hemisphere where the growing season is short. Conifers include pines, firs, spruces, larches, yews, junipers, cedars, cypresses, and redwoods. Most conifers are evergreen, retaining their leaves and photosynthesizing throughout the year. Some conifers, like the dawn redwood and tamarack, are deciduous, dropping their leaves in autumn. The needle-shaped leaves of some conifers, such as pines and firs, are adapted for dry conditions. A thick cuticle covering the leaf and the placement of stomata in pits further reduce water loss. Much of our lumber and paper comes from the wood (actually xylem tissue) of conifers.

The Mesozoic era was the age of gymnosperms

The gymnosperms probably descended from progymnosperms, a group of Devonian plants that were heterosporous but lacked seeds. The first seed plants to appear in the fossil record were gymnosperms dating from around 360 million years ago. Angiosperms arose more than 200 million years later.

4.5 Angiosperms

Recommended reading: pages 700–707 of chapter 30 in Campbell et al. (2015)

Angiosperms, commonly known as flowering plants, are vascular seed plants that produce flowers and fruits. They are the most diverse and geographically widespread of all plants, including more than 90% of plant species. There are about 250 000 known species of angiosperms. All angiosperms are placed in a single phylum, the phylum Anthophyta. The flower is the defining reproductive adaptation of angiosperms.

The flower is an angiosperm structure specialized for sexual reproduction. In many species of angiosperms, insects and other animals transfer pollen from one flower to female sex organs of another. Some species that occur in dense populations, like grasses, are wind pollinated. A flower is a specialized shoot with up to four circles of modified leaves: sepals, petals, stamens, and carpals.

The sepals at the base of the flower are modified leaves that are usually green and enclose the flower before it opens. The petals lie inside the ring of sepals. A style leads to the ovary at the base of the carpal. Ovules are protected within the ovary. Fruits help disperse the seeds of angiosperms. A fruit usually consists of a mature ovary. As seeds develop from ovules after Fertilisation, the wall of the ovary thickens to form the fruit. Fruits protect dormant seeds and aid in their dispersal.

Mature fruits can be fleshy or dry. Oranges and grapes are fleshy fruits, in which one or more pericarp layers soften during ripening. Dry fruits include beans and grains. The dry, wind-dispersed fruits of grasses are major food staples for humans. The cereal grains of wheat, rice, and maize are fruits with a dry pericarp that adheres to the seed coat of the seed. Fruits are classified according to whether they develop from a single ovary, from multiple ovaries, or from more than one flower.

Fruits are adapted to disperse seeds. Winged seeds may function as kites or propellers to assist wind dispersal. Coconuts are specialized for water dispersal. Some fruits are modified as burrs that cling to animal fur. Many fruits are edible, nutritious, sweet tasting, and colourful. These fruits rely on animals to eat the fruit and deposit the seeds, along with a supply of Fertiliser, some distance from the parent plant.

The life cycle of an angiosperm is a highly refined version of the alternation of generations common to all plants. All angiosperms are heterosporous, producing microspores that form male gametophytes and megaspores that form female gametophytes. Each pollen grain has two haploid cells: a generative cell that divides to form two sperm and a tube cell that produces a pollen tube. The ovule, which develops in the ovary, contains the female gametophyte, the embryo sac. The embryo sac consists of only a few cells, one of which is the egg.

The life cycle of an angiosperm begins with the formation of a mature flower on a sporophyte plant and culminates in a germinating seed. Anthers contain microsporangia, containing microspore mother cells that produce microspores by meiosis. Microspores form pollen grains, which are immature male gametophytes. In the ovule, the megaspore mother cell produces four megaspores by meiosis. One megaspore survives and forms a female gametophyte, or embryo sac. The pollen is released from the anther and carried to the sticky stigma of the carpel. Most flowers have mechanisms to ensure cross-pollination. The pollen grain germinates and is now a mature male gametophyte. The pollen tube grows down within the style. After reaching the ovary, the pollen tube penetrates the micropyle, a pore in the integuments of the ovule. Two sperm are discharged into the female gametophyte. One Fertilises the egg to form a diploid zygote. The other fuses with two polar nuclei in the large central cell of the embryo sac to form the triploid endosperm nucleus.

Double Fertilisation is unique to angiosperms. The zygote develops into an embryo that is packaged with food into the seed. The embryo has a rudimentary root and one or two seed leaves, or cotyledons. When a seed germinates, the embryo develops into a mature sporophyte.

Monocots store most of the food for the developing embryo as endosperm, which develops as a triploid tissue in the centre of the embryo sac. Beans and many dicots transfer most of the nutrients from the endosperm to the developing cotyledons. One hypothesis for the function of double Fertilisation is that it synchronizes the development of food storage in the seed with development of the embryo.

Double Fertilisation may prevent flowers from squandering nutrients on infertile ovules. Another type of double Fertilisation, in which two embryos are formed, has evolved independently in gymnosperms of the phylum Gnetophyta. The seed consists of the embryo, endosperm, remnants of the sporangium, and a seed coat derived from the integuments.

Until the late 1990s, flowering plants were divided into monocots and dicots on the basis of number of cotyledons or seed leaves. Current research supports the view that monocots form a clade but reveals that dicots are not monophyletic. The majority of plants traditionally called “dicots” form a clade now known as “eudicots.”

Ever since they colonised the land, animals have influenced the evolution of terrestrial plants and vice versa. Plants and animals have been important selective agents on one another. Natural selection favoured plants that kept their spores and gametophytes above the ground, rather than dropping them within the reach of hungry ground animals.

This may, in turn, have been a selective factor in the evolution of flying insects. Some herbivores were beneficial to plants by dispersing their pollen and seeds. The animals received a benefit in turn, as they ate the nectar, seeds, and fruits of plants.

Such linked adaptations, involving reciprocal genetic modifications in two species, are coevolution. The expansion of grasslands over the past 65 million years has increased the diversity of grazing animals such as horses. Grasses are C_4 photosynthesisers that spread as declining atmospheric CO_2 levels gave them a selective advantage.

4.6 Human welfare depends on seed plants

Recommended reading: pages 707–708 of chapter 30 in Campbell et al. (2015)

Flowering plants provide nearly all our food. Only six crops—wheat, rice, maize, potatoes, cassava, and sweet potatoes—yield 80% of all calories consumed by humans.

Modern crops are the products of a relatively recent burst of genetic change, resulting from artificial selection after the domestication of plants 13 000 years ago. In maize, key changes such as increased cob size and removal of the hard coating of the kernels may have been initiated by as few as five gene mutations.

How did wild plants change so dramatically so quickly? The answer is likely a combination of deliberate and unconscious selection for plants with desirable traits, such as large fruits and lack of toxins. Angiosperms also provide important nonstable foods such as coffee, chocolate, and spices. Gymnosperms and angiosperms are sources of wood, which is absent in all living seedless plants and consists of an accumulation of tough-walled xylem cells. Wood is the primary source of fuel for much of the world. It is used to make paper, and is the world’s most widely used construction material. Humans depend on seed plants for medicines.

Scientific research has identified the relevant secondary compounds in many of these plants, leading to the synthesis of many modern medicines. **Plant diversity is a nonrenewable resource.** Although plants are a renewal resource, plant diversity is not. The demand for space and natural resources resulting from the exploding human population is extinguishing plant species at an unprecedented rate. This is especially acute in the tropics, where more than half the human population lives and where population growth rates are highest. Due primarily to the slash-and-burn clearing of forests for agriculture, tropical forests may be completely eliminated within 25 years. As the forests disappear, thousands of plant species and the animals that depend on these plants also go extinct. The destruction of these areas is an irrevocable loss of these nonrenewable resources. The rate of loss is faster than in any other period, even during the Permian and Cambrian extinctions. While the loss of species is greatest in the tropics, the threat is global.

In addition to the ethical concerns that many people have concerning the extinction of living forms, there are also practical reasons to be concerned about the loss of plant diversity. We depend on plants for food, building materials, and medicines. We have explored the potential uses for only a tiny fraction of the 290 000 known plant species. Almost all of our food is based on cultivation of only about two dozen species. Researchers have investigated fewer than 5 000 plant species as potential sources of medicines. Pharmaceutical companies were led to most of these species by local people who used the plants in preparing their traditional medicines. The tropical rain forests and other plant communities may be a medicine chest of healing plants that could be extinct before we even know they exist.

4.7 Activity 4.1

Do this activity and add it to your portfolio.

Refer to your textbook and answer the following questions:

b. Name five terrestrial adaptations that contributed to the success of seed plants.
d. Compare the size and independence of the gametophytes of bryophytes with those of seed plants.
f. Explain why pollen grains were an important adaptation for successful reproduction on land.
h. Describe the life history of a pine. Indicate which structures are part of the gametophyte generation and which are part of the sporophyte generation.
j. Describe the role of the generative cell and the tube cell within the angiosperm pollen grain.
l. Explain the process and function of double Fertilisation.
n. Describe the current threat to plant diversity caused by human population growth.

4.8 Feedback on activity 4.1

b. The five terrestrial adaptations include the seed, reduction of the gametophyte generation, heterospory, ovules, and pollen.
d. Seedless vascular plants have tiny gametophytes that are visible to the naked eye. The gametophytes of seed plants are microscopically small and develop from spores in the sporangia of the parental sporophyte. The gametophytes of seed plants obtain nutrients from their parents, while the gametophytes of seedless vascular plants must fend for themselves.
f. Pollen grains were an important adaptation because the evolution of pollen allowed for pollination and contributed to the diversity of seed plants.
h. In most conifer species, each tree has both ovulate and pollen cones. The pine tree is the sporophyte. Each ovulate cone contains megasporangium. Microsporangium undergoes meiosis, producing haploid microspores that develop into pollen grains. A pollen grain enters through the micropyle and germinates, forming a pollen tube that digests through the megasporangium. By meiosis, four haploid cells are produced. One survives as a megaspore. Female egg develops. Fertilisation occurs as sperm and egg nuclei unite. The ovule becomes a seed.
j. A generative cell divides to form two sperm and a tube cell produces a pollen tube.
l. Double Fertilisation is a mechanism of Fertilisation in angiosperm in which two sperm cells unite with two cells in embryo sac to form the zygote and endosperm. One hypothesis for the function of double Fertilisation is that it synchronises the development of food storage in the seed with development of the embryo.
n. The demand for space and natural resources resulting from the exploding human population is extinguishing plant species at an unprecedented rate. Due primarily to the slash-and-burn clearing of forests for agriculture, tropical forests may be completely eliminated within 25 years.

4.9 Summary

Among others, seeds and pollen grains are key adaptations for life on land. Dominance of he sporophytes generation, the development of seeds fertilised ovules, and the role of pollen in transferring sperm to ovules are key features of a typical gymnosperm life cycle.

Flowers generally consist of four types of modified leaves: sepals, petals, stamens, and carpels. Ovaries ripen into fruits, which often carry seeds by wind, water, or animals to new locations. Flowering plants originated about 140 million years ago. Pollination and other interactions between angiosperms and animals may have contributed to the success of flowering plants during the last 100 million years.

It is no more a secret that humans heavily depend on seed plants for products such as food, wood, and many medicines. Destruction of habitat threatens the extinction of many plant species and the animal species they support.