Overview of Lecture: Plants

Bullet Points:
- plant phylogeny & diversity
- photosynthesis
- light spectral sensitivity
- alternation of generations
  - multicellular gametophyte (n)
  - sporophyte (2n)
- nonvascular mosses etc.
- vascular ferns etc
- seed plants
- flowering plants - sex
- fruit and seed dispersal
- chemical defenses
  ... and offenses!
**Plant Diversity:** Land plants evolved from freshwater green algae with many shared, derived traits - adaptations to life in land-air environment

- **vascular plants** w/ ‘plumbing’ (ch 35)
- **land plants** w/ fatty-waxy cuticle (Fig 36.14) & stomata (Fig 36.16) - conserve water

Fig. 29.4 & 29.7. The ‘Kingdom Plantae’ has been revised into a sister clade of the chara pond weed clade (Fig 29.4)

- modern *Chara* - a pond weed is in sister group to modern plants

**The mitochondrial genome** of *Chara vulgaris*: Insights into the mitochondrial DNA architecture of the last common ancestor of green algae and land plants

The Chlamydomonas Genome Reveals the Evolution of Key Animal and Plant Functions
Merchant et al. 2007 Science 318:245-250

…the Chlamydomonas genome sheds light on the nature of the last common ancestor of plants and animals
{the common ancestor is a “missing link” between plants and animals; Chlamydomonas is not a “missing link”}

Genes shared by Chlamydomonas and animals are derived from the last plant-animal common ancestor and many of these have been lost in angiosperms, notably those encoding proteins of the eukaryotic flagellum (or cilium)
Photosynthesis (ch 10): Life is powered by sunshine. Every molecular $O_2$ that we breath was once part of two $H_2O$ molecules, liberated by photosynthesis. The captured energy is released from our food and fuel.

Photosynthesis occurs in many bacteria and in chloroplasts of algae, as well as most plants; chloroplasts are ‘remains’ of ancestral prokaryotic endosymbionts.

Photosynthesis uses light energy to split $H_2O$, release $O \rightarrow O_2$, make ATP & NADPH, and put the ‘hydrate’ in carbohydrate.

2 stages:
1a capturing energy from light (ch 10.2) w/ photopigment molecules: chlorophylls & carotenoids
1b using the energy to make reducing (electron accepting) NADPH energy-storing ATP
2 the Calvin cycle (ch 10.3): using ATP & NADPH to synthesize complex organic molecules: sugars: glucose $C_6H_{12}O_6$ → starch, wood, etc.
What is in sunlight plants can use? (sec 10.2)

Light is electromagnetic energy, ‘conveniently thought of as’ a wave. Shorter wavelengths carry greater energy.

[Fig 10.6]

Light visible to human retinal pigments is a small portion of the solar spectrum. {birds & insects see down into UV}

Cyanobacteria, green algae & plants use chlorophyll a as main photopigment & chlorophyll b as an accessory. Carotenoids absorb blue-green – inefficiently.

Leaves look green because chlorophyll does NOT absorb green - it absorbs red and violet. Note: carotenoids do not absorb orange-red.

[Fig 10.9] Engleman’s brilliant 1882 experiment w/ aerobic bacteria distributing themselves along spyrogyra algae behind a prism.
Plants have sensory systems and “behavioral” responses: to crowding

**Plant sensory systems** (ch 39); red-light sensitive **phytochrome** (Fig 39.4, Fig 39.19) exists in interconvertible forms: when Pr absorbs **red** (~660nm), switches to Pfr when Pfr absorbs **far-red** (~730nm), switches to Pr

The concentration of Pfr influences stem elongation (etiolation) in shade.

**Note low ratio of red/far-red left in light passed through leaves (shade).**

Manipulative approaches to testing **adaptive plasticity**: **Phytochrome-mediated shade-avoidance responses** in plants. {text ch 39.3}


Because chlorophyll selectively absorbs red wavelengths, the ratio of **red** (R) to **far-red** (FR) wavelengths is an accurate signal of vegetation shade ...

Many plants respond to **low** R:FR with a suite of photomorphogenic changes such as stem elongation, suppression of branching, altered biomass allocation, and accelerated flowering, commonly referred to as the "shade avoidance syndrome".

Such responses are often elicited by FR reflected from neighboring plants before canopy closure, indicating that plants can detect and respond to potential future competitors ...

{**bolt** - race up high to compete for scarce light vs branch – spread out low to collect abundant light}
All plants undergo mitosis \{cell multiplication\} after meiosis \{formation of haploid spores\} resulting in a **multicellular haploid stage** \{unlike animals\}: **gametophyte** \(n\) as well as a multicellular diploid stage \{as in animals\}: **sporophyte** \(2n\) - called ‘haplodiplotonic’ **alternation of generations** (Fig 29.5)

Fossilized plant **spores** on land ~ 500 mybp. Sporopollenin in wall is the most durable organic material known.

The multicellular **diploid sporophyte** produces haploid spores not gametes, by meiosis.

The multicellular **haploid gametophyte** produces haploid gametes by mitosis. Gametophyte is non-vascular & either confined to moist spots or small.

\{if you were a plant, would you be a sporophyte, gametophyte or both?\}
Unlike animals, land plants undergo an alternation of generations, producing multicellular bodies in both haploid (1n: gametophyte) and diploid (2n: sporophyte) generations.

In mosses, the haploid gametophyte generation is dominant, whereas in vascular plants—including ferns, gymnosperms, and angiosperms—the diploid sporophyte generation is dominant.

The closest living relatives of land plants are green algae that lack an alternation of generations. Their only organismic {multicellular} generation is a haploid gametophyte; after fertilization and the formation of a diploid zygote, meiosis creates haploid propagules that reestablish new gametophytes.

Thus, the only diploid phase in the life cycles of the ancestors of land plants was the single-celled zygote.

The multicellular sporophyte as we know it (such as a leafy fern, pine tree, water lily, and buttercup) is a developmental innovation of land plants. {note: multicellular diploid gamete forming body in animals – such as yourself!}

The KNOX2 gene plays a critical role in the development of a multicellular diploid sporophyte in land plants. {by suppressing it}
nonvascular **Bryophytes** (mostly mosses)

**Key**
- Haploid \((n)\)
- Diploid \((2n)\)

- Protonemata \((n)\)
- Spores
- Male gametophyte \((n)\)
- Female gametophyte \((n)\)
- Rhizoid
- Spore dispersal
- Peristome
- Sporangium
- MEIOSIS
- Capsule (sporangium)
- Seta
- Foot
- Mature sporophytes
- Young sporophyte
- Female \((2n)\) gametophytes
- egg
- Antheridia
- Sperm
- “Bud”
- Gametophore
- Capsule with peristome (SEM)
- *FERTILIZATION (within archegonium)*
- Zygote \((2n)\)
- Embryo
- Archeogonium
- Archeogonium
- Capsule (sporangium)
- Mature sporophytes
- Sphagnum - future peat; Defrosting the Carbon Freezer of the North

- moss
- liverwort
- hornwort
- gametophyte \((n)\) dominates
- seedless vascular plants
- Gymnosperms
- Angiosperms
- Nonvascular plants

Copyright © 2008 Pearson Education, Inc., publishing as Pearson Benjamin Cummings.
Sexual reproduction in non-vascular plants requires unicellular free-motile sperm to travel from male to female reproductive structures across the terrestrial landscape.

Here we show that tissues of the cosmopolitan moss Ceratodon purpureus emit complex volatile scents, similar in chemical diversity to those described in pollination mutualisms between flowering plants and insects, that the chemical composition of C. purpureus volatiles are sex-specific, and that moss-dwelling microarthropods \(\text{springtails \& mites}\) are differentially attracted to these sex-specific moss volatile cues.

Furthermore, using experimental microcosms, we show that microarthropods significantly increase moss fertilization rates, even in the presence of water spray, highlighting the important role of microarthropod dispersal in contributing to moss mating success.

Taken together, our results indicate the presence of a scent-based ‘plant–pollinator-like’ relationship that has evolved between two of Earth’s most ancient terrestrial lineages, mosses and microarthropods.
How tall can a tree grow? ... researchers ... have placed the theoretical height limit at 130 metres: the height of a 35-storey skyscraper. ... Koch et al. 2004. *Nature*, 428, 851-854.
vascular Ferns, horsetails & club mosses: roots & shoots; no seeds
Seed plants are vascular plants that produce seeds. The two clades of seed plants are **gymnosperms**: non-flowering, ‘naked ovules’; seed **angiosperms**: flowers w/ ovules in carpels; seeds in fruit.

Three important reproductive adaptations: **reduction of the gametophyte**, {micro- & megaspores} **the advent of the seed**, and **the evolution of pollen**.

<table>
<thead>
<tr>
<th>Phylum</th>
<th>Examples</th>
<th>Key Characteristics</th>
<th>Approximate Number of Living Species</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>SEED PLANTS</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Anthophyta</td>
<td>Flowering plants (angiosperms)</td>
<td>Heterosporous. Sperm not motile; conducted to egg by a pollen tube. Seeds enclosed within a fruit. Leaves greatly varied in size and form. Herbs, vines, shrubs, trees. About 14,000 genera.</td>
<td>250,000</td>
</tr>
<tr>
<td>Coniferophyta</td>
<td>Conifers (including pines, spruces, firs, yews, redwoods, and others)</td>
<td>Heterosporous seed plants. Sperm not motile; conducted to egg by a pollen tube. Leaves mostly needlelike or scalelike. Trees, shrubs. About 50 genera.</td>
<td>601</td>
</tr>
<tr>
<td>Cycadophyta</td>
<td>Cycads</td>
<td>Heterosporous. Sperm flagellated and motile but confined within a pollen tube that grows to the vicinity of the egg. Palmlike plants with pinnate leaves. Secondary growth slow compared to that of the conifers. 10 genera.</td>
<td>206</td>
</tr>
<tr>
<td>Gnetophyta</td>
<td>Gnetophytes</td>
<td>Heterosporous. Sperm not motile; conducted to egg by a pollen tube. The only gymnosperms with vessels. Trees, shrubs, vines. Three very diverse genera (<em>Ephedra, Gnetum, Widdringtonia</em>).</td>
<td>65</td>
</tr>
<tr>
<td>+ Ginkophyta</td>
<td>Ginko tree</td>
<td>male trees OK, female fleshy seeds (not fruit) a mess!</td>
<td>1</td>
</tr>
</tbody>
</table>
Double fertilization: (ch 38.2)

1. of 1n egg: diploid 2n zygote
2. of 2x1n double haploid cell: triploid 3n endosperm

Endosperm (3n) is the bulk of cereal grains (grasses: corn, wheat, rice, barley) which directly or indirectly (meat, beer) provide most human nutrition.

Beans have converted 3n endosperm into 2n embryo.

Pillow talk in plants
**Fruits** are mature ovaries that contain seeds (ch 38.2)

- **Drupes**
  - Single seed enclosed in a hard pit; peaches, plums, cherries.

- **True berries**
  - More than one seed and a thin skin; blueberries, tomatoes, grapes, peppers.

- **Hesperidia**
  - More than one seed and a leathery skin; oranges, lemons, limes.

**Aggregate fruits**
Derived from many ovaries of a single flower; strawberries, blackberries.

**Multiple fruits**
Develop from a cluster of flowers; mulberries, pineapples.

**Pomes** - include: apples, pears & quinces.
The core is the ovary (maternal) with seeds (partly maternal, partly recombinant), and the rest (the tastee part) is overgrowth of receptacle (maternal).

Note: For mamma plants, carbohydrate is cheap but nitrogen is dear.

**Seeds** are babies, packed w/ scarce protein & protected from digestion; **fruits** are cheap high-sugar low-protein maternal tissue; enticements to animal dispersers.

If you find a tastee new mutant variety of apple, can you plant the seeds to propagate the variety?
Plant Manipulation

Many plants have ripe, fleshy, coloured fruit in order to attract animals that will eat them and then disperse their seeds in droppings. However, the chilli plant has developed another way of ensuring its seeds are spread far and wide.

What raises the roof of your mouth when you eat a chilli is a substance called capsacin. This stimulates the areas of the skin and tongue that normally sense intense heat and pain, falsely telling the brain that the area affected is burning.

New research ... has discovered that this characteristic peppery taste repels certain animals {mammals} – which are no good at dispersing the seeds.

Digestion And Dispersal

... scientists observed ... animals living around a group of wild-growing chillies in Arizona. ... desert mice and rats avoided spicy chillies, but birds fed almost exclusively on the plants. ... when birds ate the chillies, many seeds germinated, but there was no germination after mice had eaten the chilli seeds. ... seeds pass through a birds’ digestive systems very quickly and come out unharmed, whereas in mice, rats and other mammals, the seeds don’t make it out in one piece ... The researchers suggest that chilli plants have evolved to produce capsaicin as a repellent for animals {mammals} ... whilst still allowing birds to eat their seeds.

Molecular basis for species-specific sensitivity to "hot" chili peppers.
Jordt & Julius 2002. CELL 108:421-430. {the vanilloid receptor subtype 1 (VR1)}
In terrestrial habitats, the resources that a photosynthetic organism needs are found in two very different places. Light and carbon dioxide are mainly aboveground; water and mineral nutrients are mainly in the soil. Though plants cannot move from place to place, the elongation and branching of their shoots and roots allows them to ‘forage’ for resources. This growth in length is sustained by the activity of **apical meristems** localized regions of cell division at the tips of shoots and roots.

**Grasses** have apical meristem at the base, so growth isn’t disrupted by grazing or mowing.
Grasses are modern, specialized (derived) flowering plants. Most grasses are pollinated by wind, so that their flowers are highly reduced … All the world’s cereal crops are grasses. The top 4 food crops are grasses: sugar cane, corn, wheat, rice. Human well-being depends on \{the 3n endosperm in\} in the cereal grains corn, wheat, rice - & barley.

Grass plants and grazing mammals appeared in the fossil record at the same time in the lower Miocene Epoch about 20 million years ago. \{recent!\} and have evolved together.

Another economically significant use of grasses is lawns … grasses are well adapted for use in lawns, because their basal meristems (growing points) are not lost with mowing. \{or grazing, or burning - used in prairie restoration\}
Plants are sensitive creatures!

In touch: plant responses to mechanical stimuli.
Braam J 2005 NEW PHYTOLOGIST 165:373-389

Perception and response to mechanical stimuli are likely essential at the cellular and organismal levels. Elaborate and impressive touch responses of plants capture the imagination as such behaviors are unexpected in otherwise often quiescent creatures.

Touch responses can turn plants into aggressors against animals, trapping and devouring them, and enable flowers to be active in ensuring crosspollination and shoots to climb to sunlit heights.

Signaling molecules and hormones have been implicated in touch responses.

Remarkably, touch-induced gene expression is widespread; more than 2.5% of Arabidopsis genes are rapidly up-regulated in touch-stimulated plants. Many of these genes encode calcium-binding, cell wall modifying, defense, transcription factor and kinase proteins. ...
Plants have evolved a variety of defensive mechanisms to reduce damage from attack by viruses, bacteria, fungi, animals and other plants.

Plants have (or induce) toxins to poison herbivores, ex: cyanogenic glycosides & alkaloids also phytoestrogens (ex in soy)

Herbal & folk medicines exploit these, including for disease control: ex: quinine & taxol

Ethnobotany/ethnopharmacology and mass bioprospecting: Issues on intellectual property and benefit-sharing

Soejarto et al. 2005
J. Ethnopharm 100:15-22

Spices – tickle tongue & kill pathogens!
Bitter Taste Identifies Poisons in Foods

Scientists at the Monell Chemical Senses Center report that bitter taste perception of vegetables is influenced by an interaction between variants of taste genes and the naturally-occurring toxins in the vegetable.

Scientists have long assumed that bitter taste evolved as a defense mechanism to detect potentially harmful toxins in plants. Glucosinolates in some plants act as anti-thyroid compounds ... inhibit iodine uptake. ... 35 healthy adults were genotyped for the hTAS2R38 bitter taste receptor gene; the three genotypes were PAV/PAV (sensitive to bitter-tasting PTC), AVI/AVI (insensitive), and PAV/AVI (intermediate).

Subjects then rated bitterness of various vegetables; some contained glucosinolates (broccoli, bok choy, kale, kohlrabi, & turnip) while others did not (radicchio, endive, eggplant and spinach). Subjects with the sensitive PAV/PAV form of the receptor rated glucosinolate-containing vegetables as 60% more bitter than did subjects with the insensitive (AVI/AVI) form.

“The sense of taste enables us to detect bitter toxins within foods, and genetically-based differences in our bitter taste receptors affect how we each perceive foods containing particular toxins.”
**Induced defenses**: (sec 39.5) Plants allocate more to defense after attack.  

[see: http://dogbert.gi.alaska.edu/ScienceForum/ASF7/762.html](http://dogbert.gi.alaska.edu/ScienceForum/ASF7/762.html)

... and warn their neighbors!  
(“Talking Trees”)

**Sometimes they call for help!** (Fig 39.29)  
Herbivore-infested plants selectively attract parasitoids.  
De Moraes et al. 1998. NATURE 393:570-573.

... but “predators” might be eavesdropping!

**News of the Week: **Parasitic Weed Uses Chemical Cues to Find Host Plant  
Elizabeth Pennisi Science 2006 313, p. 1867  
Dodder may be the bloodhound of the plant world.  
A plant that parasitizes other plants, it sniffs out its victim ...

**Volatile Chemical Cues Guide Host Location and Host Selection by Parasitic Plants**  
JB Runyon et al. 2006.  
Science 313, 1964.
We use the **tobacco hornworm**, *Manduca sexta*, and its interactions with the **wasp parasite** *Cotesia congregata* as a model system ...

**This parasite injects a large, multi-segmented DNA virus, a polydnavirus, into the host during parasitization.**

Viral sequences are integrated in the genomic DNA of the parasite and the **PDV is a symbiont of the wasp.**

Following oviposition, the virions enter host cells and become transcriptionally active.  
... **cause host immunosuppression**, which allows the parasites to develop ...

Parasitoids and polydnaviruses.  