October 24 – Secondary metabolites

Primary metabolites: molecules that are found in all living plant cells and are necessary for life (examples that should be familiar to you: ATP, glucose, amino acids, proteins, DNA, phospholipids, etc).

Secondary metabolites: restricted in distribution, not in all living cells of plants. Not immediately necessary for cell function. At one point considered waste products by botanists. Now understood to have benefits – but they not always known or apparent!

Three broad classes of secondary metabolites:
I. Terpenoids (a.k.a., terpenes; >22,000 isolated)
II. Alkaloids (>10,000 different compounds isolated)
III. Phenolics (many 1000's identified)

We will learn about 12 secondary metabolites today, a few from each of the three major groups:

I. Terpenoids (a.k.a., terpenes)

- Largest class of 2° metabolites (over 22,000 different compounds described)
- All are constructed of the chemical subunit **isoprene**, which itself is a terpenoid

1) Isoprene

- Subunit of all terpenoids
- Isoprene monomers exist as a gas emitted by plants on especially hot days, and are responsible for the blueish haze over forests on summer days.
- Potential benefits are unknown, but may either reflect light or chemically stabilize chloroplast membranes damaged by heat. Then again, single isoprenes might be a waste product!

2) Essential oils

- Called 'essential' because they impart the 'essence' of a plant.
- "Volatile" – they evaporate and become airborn at a low temperature
- Key for **attracting** or **repelling** animals from plants – attracting in the case of pollinators or seed dispersers and repelling in the case of potential herbivores (recall mint leaves applied to bee hives – the point here was that the tracheid mites were repelled from a bee's trachea…)
- Examples are many, we discussed carvone/menthol (mint); limonene (citrus); eucalyptol (eucalyptus) and lavender oil (we passed this around in lecture).
- Eucalyptus are also **allelopathic,** due to essential oils

Allelopathy: The inhibition of one plant species by the chemicals produced in another plant species

3) Rubber

- Obtained commercially from **latex** of tropical plant *Hevea brasiliensis*
- **Largest of all terpenoids** – up to 100,000 isoprene units long!!
- {Video of caterpillar/latex interaction: BBC's Life "plants" 18:15-19:10}
- Charles Goodyear (he of tire fame…) among first to apply industrial-scale vulcanization

Latex: a milky fluid found in 10% of all flowering plants. It is a complex emulsion consisting of proteins, alkaloids, starches, sugars, oils, tannins, resins, and gums that coagulate upon exposure to air. It is usually exuded after tissue injury. It serves mainly as defense against herbivorous insects, and heals (covers and protects from infection) plant wounds.

II. Alkaloids

- Nearly 10,000 identified
- Contain N atom in a ring (with C atoms), taste bitter
- Well known because many have pharmaceutical or narcotic use
- Names end in "_____–ine"!!

1) Morphine

- Isolated from latex of the **opium poppy** *Papaver somniferum;* seed pods are slit and the milky latex (raw opium, ~12% morphine) is collected. This opium is dried and can be smoked or ingested. Medical grade morphine is processed from opium. Morphine can be chemically altered (acetylated) to produce **heroin**, which is 1.5 times more potent than morphine itself.
- First recorded cultivation is by **Sumerians** in Mesopotamia in ~ 3500 BC, who referred to the plant as *jul gil* ("joy plant"). Egyptians grew it by 1300 BC, was then passed down through the ages across many cultures. Abuse of opium became widely reported in Chinese opium dens during 1800s.
- Used as a strong pain reliever, we discussed '**sponga somnifera**' as an early form of anesthesia. Bayer Pharmaceutical's Heroin: on market from 1898 - late 1920's/30's as pain relief and cough supressent. Morphine still used widely as pain killer.
- Gooey latex loaded with morphine seems like a great anti-herbivory compound! Poppy seeds are tiny (think of a poppy-seed bagel!) and likely distributed by physical forces once the seed pods rupture (thus animal seed dispersers are not needed…).

2) Cocaine

- Isolated from **coca plant** (*Erythroxylum coca*), a small woody plant native to the **Andes Mountains in South America.**
- Incas chew (and have for 1000's of years…) for extra energy at high elevation – leaves contain small amounts of cocaine and chewing leaves is much more responsible, and less addictive and damaging, than smoking, snorting or injecting of cocaine concentrated from the leaves
- History of medical use as an anesthetic by dentists and in eye surgery
- Yes, was actually an ingredient in early formulations of Coca-Cola!
- Probably an anti-herbivory compound

3) Caffeine

- Found in coffee (*Coffea arabica*) tea (*Camellia sinensis*) and cocoa (*Theobrama cacao*)
- Caffeine is extremely toxic!! Large doses can kill - mechanisms under debate but appear to be associated with cardiac arrest in mammals
- High concentrations in seedlings are lethal to insects and fungi, and are also allelopathic to other plants
- Most widely used psychoactive drug in the world

4) Nicotine

- Obtained from tobacco (*Nicotiana tabacum*)
- Highly toxic to insects and fungi {VIDEO: http://www.youtube.com/watch?v=dfmgpA3x0e4}
- Insecticides – nicotine sulfate, sold under the trade name "**Black Leaf 40**"
- Nicotine kills by causing paralysis and suffocation b/c it inhibits normal nerve function

5) Theobromine

- Occurs in the seeds of, and is named after, the cacao plant *Theobroma cacao* (Gr: theos = "God" + broma = "food"). (Also in other plants such as coffee (*Coffea arabica*) tea (*Camellia sinensis*.)
- Cacao seeds are the primary ingredient in chocolate (along with sugar and in some cases milk)
- Theobroma cacao - Native to Central and South America
- Early forms of chocolate were pioneered by and important to Mesoamerican cultures such as the Maya, Inca, Olmec, and Mixtec
- We discussed the steps of modern chocolate making: 1) harvesting cacao fruits and separating out seeds & "pulp", 2) fermentation, 3) drying, 4) roasting, 5) cracking and winnowing, 6) conching & blending, and 7) finishing & molding. I am unlikely to ask you about these sequence and purpose of these specific steps
- Theobromine causes chocolate poisoning – most commonly in dogs because: 1) when they get their paws on chocolate they eat until it's all gone(!!), and; 2) their bodies cannot metabolize ("break down") theobromine as quickly as humans can.

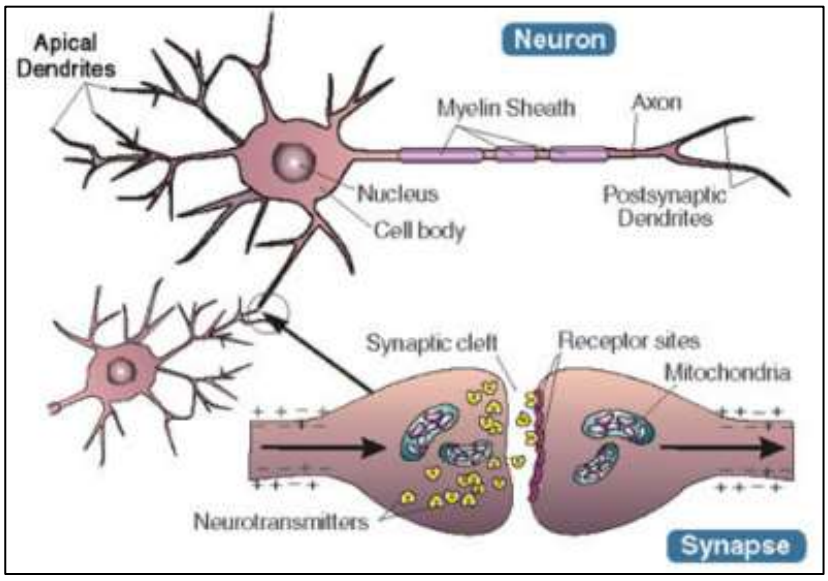
6) Capsaicin – a "pseudo-alkaloid" (slightly different molecular structure than "typical alkaloids – no need to know this structural detail)

- Produced in peppers – it's the compound that makes them hot
- **Scoville scale** – a relative scale of pepper pungency or "hotness". Ranges from zero (sweet bell peppers) to over 1 million (Bhut Jolokia, Carolina reaper, and others,).
- We watched the top video of the effects of bhut jolokia – the ghost pepper: http://www.youtube.com/watch?v=1tRq8ExAHzk http://www.youtube.com/watch?v=ZstObB4RVsQ (this video is funny too, but NSFW!)
- Capsaicin is fat soluble – drinking water to cool your palate after accepting the wrong pepper-eating challenge will not do you any good!
- Capsaicin protects seeds from mammals, but **birds NOT affected by capsaicin**. Hot peppers appear to have an evolutionary partnership with birds for seed dispersal! (Birds can't "chew" – they don't have teeth! Thus more seeds pass through undamaged!)

Most alkaloids excite or inhibit neurons, and they specifically do so at synapses. Specifically, alkaloids mimic neurotransmitters, or they act directly upon the neurotransmitter receptor sites (either inhibit or excite them). There are lots of interesting mechanisms by which this latter impact occurs. (You will learn much more about neurons, neurotransmitters, and synapses in Bio102 and Bio103. When you do, please recall our exploration of alkaloids!)

The excited or inhibited impulse can then cause failure of the muscles/organs innervated by the impacted neurons. A common example is cardiac arrhythmia or cardiac arrest.

Synapse: a junction between two nerve cells, consisting of a minute gap across which impulses pass by diffusion of a neurotransmitter.



III. Phenolics

Defined as containing an –OH group attached to a an aromatic ring (6 C atoms in a ring)

1) Tannins

- **Widespread** - likely the most common and important **anti-herbivory compounds** in plants; they function by binding to and **denaturing ingested plant material proteins and inhibiting digestion** in the gut.
- We saw them in lab in heartwood (wood lab), and we will see them in conifer leaf cross sections (gymnosperm lab)
- Used by humans to "tan" hides – this denatures the proteins in skin (collagen) and prevents bacterial attack
- Tannins cause the **"tea-colored" hue to forest streams** as they (the tannins) leach out of fallen leaves on the forest floor

2) Lignins

- In **secondary cell wall**
- Give **cell walls strength** needed to allow plants to grow large – without lignin the tallest of trees would be much shorter :(…
- Highly **resistant to decay** by fungi
- Likely the **most abundant secondary plant metabolite** on Earth (I can't find a reference for this, but I am 99% certain that it's true!!!)

3) Salicylic acid

- Found in bark of **willow trees**
- Name 'salicylic acid' derives from the willow genus name *Salix*
- Used by ancient Greeks, Egyptians, and Native Americans, among other human cultures, (and wild animals?) as a pain killer
- Chemical precursor to **aspirin** (acetylsalicylic acid)– one of the most important drugs in human history

Tips for studying this material: Know the fundamental biochemical differences among the three categories presented here (phenolics vs. terpenoids vs. alkaloids). That being said, It is UNlikely that I will ask you to place each of the 12 metabolites in their proper category (phenolic, terpenoid, or alkaloid…well except for alkaloids…you need to know which of the the molecules discussed above is an alkaloid). Most important to me is that you understand the origin (plant from which each is isolated), activity in nature (i.e., how each is adaptive for plants that produce them), and any human applications or hazards. Emphasize the bolded term throughout these notes.