March 7 – Function of xylem and phloem

We have examined the location of xylem and phloem in plant organs: roots, stems, and leaves. We have also defined these two types of vascular tissue:

Xylem: vascular tissue through which water and nutrients are transported (from roots to stems/leaves).
Phloem: vascular tissue through which sugars are transported from sources to sinks. Sources are typically photosynthetic tissues such as leaves, but can also be storage organs when starch is broken down and its sugars are mobilized. Sinks are any tissues that require sugars.

In order to understand structure and function of xylem and phloem, the following information is pertinent:

- Mature xylem cells are sclerenchyma (they have a secondary cell wall) and they are dead.
- Phloem cells are parenchyma (thin primary cell wall, no secondary cell wall) and they are alive at maturity.

Primary cell walls: constructed from a cellulose framework that is "filled in" with two other polysaccharides: hemicellulose and pectin. (Unlike cellulose and starch, these are complex polysaccharides that are not polymers of glucose – they are constructed from multiple different subunits and we will not detail them – you do not need to know their structure).
Primary walls can be plastic and they are **permeable to water** (the primary wall slows water flow, but water can still flow though thin primary cell walls).

Secondary cell walls: These are thickened and made from the same material as primary cell walls, but also contain a very strong molecule called **lignin**. The thickness and lignin content of secondary cell walls makes them very strong and **impermeable to water**.

Middle lamella: pectin-rich layer that cements together neighboring cells (along their primary cell walls).
Pectin: polysaccharide in 1° cell walls and middle lamella. Humans extract pectin from plants and use it as a gelling (i.e., thickening) agent in food production (e.g., jams and jellies). More on pectin later…

There are two types of xylem cells: 1) tracheids, and; 2) vessel elements

Tracheid: elongated, thick walled, tapering, pitted (with pit-pairs forming between neighboring tracheids), **no perforation** (no complete hole in the primary cell wall). Evolved before flowering plants – present in ferns, gymnosperms (conifers etc.), and angiosperms (more on these groups later this semester).

Pit: location on a tracheid/vessel element where the secondary cell wall is absent, allows water to flow through

Pit pair: a physical alignment of pits on neighboring tracheids or vessel elements that allows water to flow between tracheids/elements

Vessel element: xylem cells that **contain perforations** (complete holes in the primary and secondary cell walls) and **perforation plates** (see definition below) at each end. Vessel elements stacked end-to-end form **vessels**. The perforations allow for more efficient flow of water compared to tracheids. Tracheids evolved first, vessels later – apparently about the time that flowering plants evolved as they are in most flowering plants (angiosperms) but no gymnosperms.

Perforation: small holes or slits in vessels where the primary and secondary cell walls have been completely dissolved.

Perforation plate: The end wall of vessel cells (a.k.a., vessel elements) where cell walls (both the primary and secondary) have been dissolved and through which water freely flows.

Vessel: a stack of vessel elements that form a long tube. (Does not run entire length of plant, thus water needs to move laterally through pits in side of vessel elements and enter new vessels in order to make it to the top of the tree).

Tracheids and vessel elements need to be reinforced (i.e., have secondary cell walls) because they are under immense strain as water is pulled upwards from the roots to leaves – the effect of the pressure is not unlike the effect upon a flimsy straw as you attempt to slurp up a thick smoothie or milkshake and cause the straw to implode.

Injury to xylem

What if tracheids or vessels are punctured/broken? Well, this is disastrous because air could flow into other tracheids and vessel elements – thus rendering a vessel unable to transmit water upwards. The pits serve to isolate embolisms (air pockets) and re-route water flow through two mechanisms:

1) Air isolated by pit "membranes" (primary cell wall and middle lamella) and H_2O surface tension that isolates the embolism. Video demo. of surf. Tension: (http://www.youtube.com/watch?v=u5AxlJSiEEs)
2) Tori (singular = Torus: a plug in bordered pit pairs. (Know structure/function as we drew in class, if we had time).

We may or may not have had time to cover these concepts in lecture. If we did not, then you are not responsible for knowing this material on upcoming assessments. However, I might ask you about how a torus works as an extra credit question.

Water transport in xylem – from "soil to stomata". We diagrammed the journey of water molecules as they enter roots, travel upwards though xylem, and exit stomata. You should know the individual steps and physical/chemical processes involved. I am intentionally excluding that detail from these notes, but this is a guaranteed exam question – if you took poor notes, seek out a classmate for assistance. (By the way: The process of water moving through a plant from root to leaves is often called **transpiration**, and that's OK for our purposes, but be aware that technically transpiration is defined as: the loss of water vapor by plant parts.)

Cohesion-tension theory (aka **transpiration**; explains how water is transported up xylem)
Cohesion: attraction between like molecules
Adhesion: attraction between/among unlike materials or molecules
Tension: the stress resulting from the elongation of an object or material
{Video: 'transpiration': http://www.youtube.com/watch?v=mc9gUm1mMzc}
{PLOP 'growing' 11:16 – 14:30}

Transport of sugars in phloem

Phloem also is comprised of two cell types: 1) sieve cells, and 2) companion cells (*note: this is a slight simplification that we will embrace, and that is common in botany courses at many levels):

Sieve cell/sieve tube cell: Phloem cells through which sap travels. Sieve cells are short and have pores that are clustered at the end walls in structures called **sieve plates.** (sieve pores are enlarged plasmodesmata, and thus different in origin and smaller than perforations in vessel perforation plates). As with pits in vessel elements, these pores allow for efficient transfer of liquid. Sieve cells have no nucleus.

Sieve plates: end walls that are high in pores in the top of sieve cells that allow for efficient transfer of water from sieve tube cell to sieve tube cell.

Sieve tube: a long chain of sieve cells stacked end-to-end, forming a long tube for transporting phloem sap.

Companion cells: Narrow cells associated with sieve cells, and which provide for sieve cells the support/services (e.g., protein synthesis) required of a living cell. Companion cells also have a key role loading sugars into/out of sieve cells. These are the small cells we see in cross sections of phloem.

Ant-aphid interactions on plants:

Aphids are common garden pests that puncture the phloem of plants and drink the water that contains high [sucrose], (often referred to as "sap"). They ingest this high [sucrose] water in excess and excrete it out of their backsides as a secretion called honeydew.

Honeydew: the sweet secretion of aphids that are tapped into phloem

Aphids secrete the honeydew in order to attract ants that drink the honeydew, and in return the ants protect the aphids from predators. This ants, are said to "herd" aphids much the same was a shepherd might protect sheep from wolves or other predators. When ants do this, agriculturalists/horticulturalists refer to this as the ants "running the plant". It can be very difficult to eliminate the aphids without addressing the ant population as well.

Not covered in class – possible extra credit on exams?

Dealing with phloem damage (embolism): P-protein and callous:

If a sieve tube is breached (e.g., by a chewing insect) then the damage can be localized. This is accomplished by plugging the sieve plates on damaged sieve cells. This plugging is initiated by the drop in pressure caused by injury. The materials that plugs the sieve plates are 1) P-protein (P = phloem), or; 2) callous. Both are 'stringy' or diffuse proteins present in the sieve cells that become solid in response to low pressure. If damage were not isolated, the plant could lose function of an entire sieve tube – that would be bad!!

Not covered in class – possible extra credit on exams?

Phloem function – the **pressure-flow hypothesis.**

The pressure-flow hypothesis explains how sugars are transported in the phloem. Here are the basics, as discussed in class:

1) sugars are actively pumped ("actively" means that ATP is burned to pump the sugars across a cell membrane/membranes) from **sources** to companion cell/sieve cell complexes. This process is **phloem loading**.
2) high [sugar] and thus lower [water] in sieve cells results in osmosis of water from outside sieve cells into the sieve cells. This water entering via osmosis can originate from xylem – but sugars do not enter xylem.
3) increased pressure at site of phloem loading and osmosis causes flow in sieve cells that is away from site of phloem loading.
4) sugars flow away from site of phloem loading
5) when sugars arrive at **sinks** they are used immediately or 'unloaded' into sinks for future use
6) water returns to the xylem or otherwise exits the sieve tube once solute (sugar) concentrations are lowered due to unloading

Source: Tissue that produce more sugars than are used. Typically leaves during photosynthesis, but can also be storage organs such as carrots, potatoes.

Sink: Cell or tissues that use more sugars than they produce.

Phloem loading: the process by which sugars are actively pumped from source into sieve cell/companion cell complexes.

{Video of pressure-flow hypothesis: http://www.youtube.com/watch?v=MxwI63rQubU (0:50-2:28)}
{Video of pressure-flow hypothesis: http://www.youtube.com/watch?v=-b6dvKgWBVY}