Jan 23 - Carbohydrates

Despite the vast diversity of life on Earth and the ~92 naturally occurring elements (see periodic table), the large molecules essential to and built by living organisms are relatively few in number. They are called biomolecules:

Biomolecule: any molecule that is essential to cell structure and function and produced by a living organism.

Some biomolecules are small (e.g., vitamins, hormones), but we will explore four types of large biomolecules, they are:

1) Carbohydrates (today's lecture)
2) Proteins (next week in lecture)
3) Lipids (week 3 or 4 in lab, consult syllabus)
4) Nucleic acids (later in the semester…)

In today's lecture we consider carbohydrates, and we'll explore proteins, lipids, and nucleic acids in future lectures/labs.

Carbohydrates (can you infer why from the molecular structure?)
There are three different categories of carbohydrates:

1) Monosaccharides* (mono: *one* + sakkharon: *sugar*)
2) Disaccharides* (di: *two* + sakkharon: *sugar*)
3) Polysaccharides (poly: *many* + sakkharon: *sugar*)

As with most other aspects of biology, the form (i.e., structure) of different sugar molecules directly relates to their function (form and function at a molecular scale – how cool!).

** mono- and disaccharides are referred to as "sugars"*
**note that almost all carbohydrates have names that end in "-ose" (see examples below)*

Monosaccharides: (single unit sugars; the smallest sugar molecules). Fuel source for cells (especially true of glucose). When C-C bonds are broken, energy is released. Monosaccharides are the smallest carbohydrate molecules. Larger carbohydrates molecules are constructed by linking together individual monosaccharides.

Glucose ($C_6H_{12}O_6$): THE primary fuel source for cells – stay tuned!! Glucose is the main product of photosynthesis and is broken down as a cellular fuel during respiration. It also the monomer of many polysaccharides.
Glucose exits as two ring forms; the alpha (α) and beta (β) configurations.
Be able to draw the α and β ring forms of glucose.
Glucose is also the sugar transported in the blood of animals…hence "blood sugar"

Fructose ($C_6H_{12}O_6$) – but with a different structural formula than glucose. ("fruit sugar"; sweetest of all sugars listed here…). Found in fruits and in the nectar of some plants – why? No need to be able to draw the structural formula (chain or ring) in atomic detail – but recognize it as a simple pentagon when labeled.

Ribose ($C_5H_{10}O_5$) – found in RNA and ATP, also the deoxygenated form (deoxyribose) found in DNA (O absent from C2 of ribose). Know where it's found, no need to be able to draw structural formula in atomic detail (but we'll draw it as a simple pentagon when we discuss ATP).

<u>Disaccharides</u> (two unit sugars) are formed by linking together two monosaccharides.

Maltose = glucose + glucose (malt sugar). The glucose molecules are α-glucose and are bonded together at C atoms 1 and 4 (this bond is thus called an α-1,4 bond or α-1,4 linkage). We'll discuss maltose and its importance in brewing later in the semester.

During today's lecture, we discussed how maltose is formed from, or broken apart into, individual α-glucose molecules. The chemical reactions involved were **condensation reactions** (aka condensation synthesis) and **hydrolysis reactions**. Know these.

Sucrose = glucose + fructose ("table sugar"). Common in many plant parts, sucrose is the "transport sugar" – that is to say sugars are moved about the vascular tissue of a plant primarily as sucrose.

Commercial sources of sugar in include mature stems ("stalks") of sugar cane (*Saccharum* spp., POACEAE) or the fleshy taproot of sugar beets (*Beta vulgaris*; AMARANTHACEAE). Sugar cane is grown in tropical regions and accounts for >70% of sucrose production. Sugar beets are grown in temperate regions and account for <30% of sucrose production. [FYI: The former is ~15% fiber, 15% sugar, and 65 % water, the latter is 70% water, 25% sucrose, and 5% pulp. Cane is tropical and beets temperate. The basics of production are as follows: the plant parts are pressed, water is allowed to evaporate out of the liquid that is obtained, and sucrose remains!]

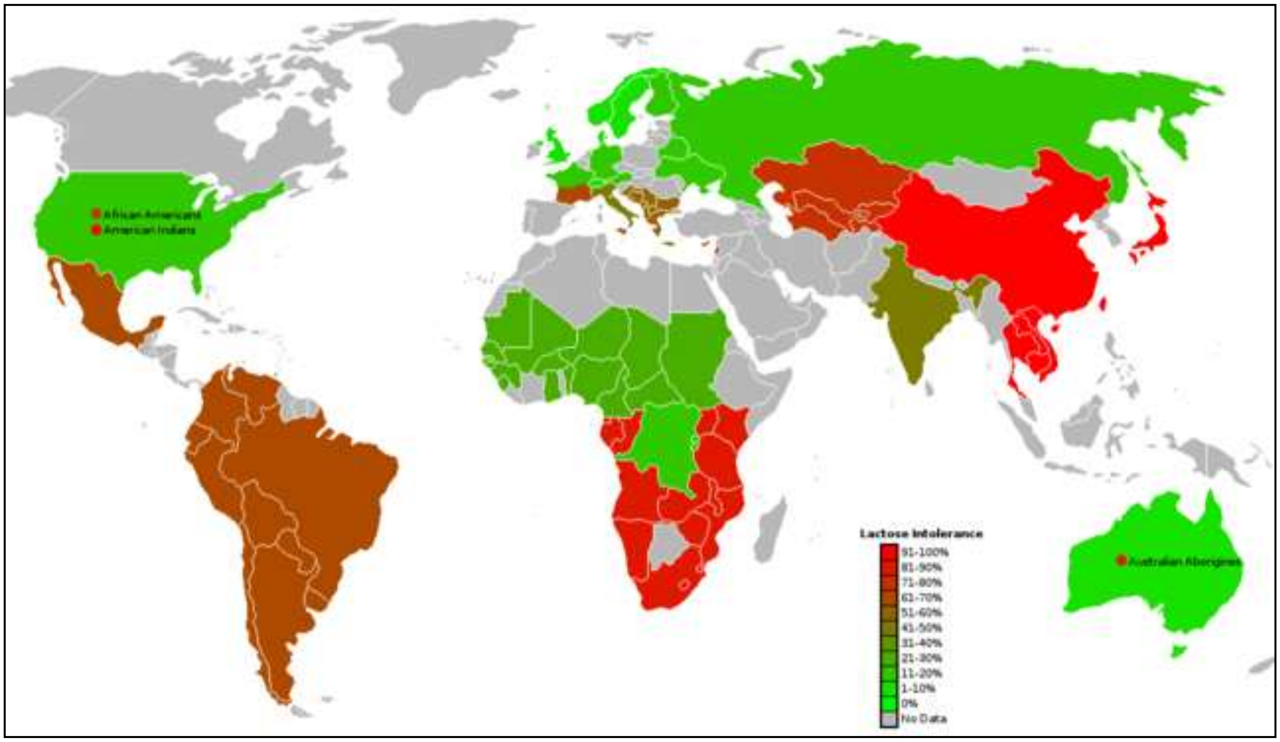
Maple syrup is mostly sucrose, but contains minerals and other sugars. Its production from the sap of maple trees (*Acer* spp., SAPINDACEAE) was described in lecture.

Sucrose is also a major constituent of nectar in flowers of many plants.

Lactose = glucose + galactose. Lactose ("milk sugar"; 2-8% of milk by weight). Although lactose is absent from plants (and your textbook), it is an important disaccharide that we will discuss.

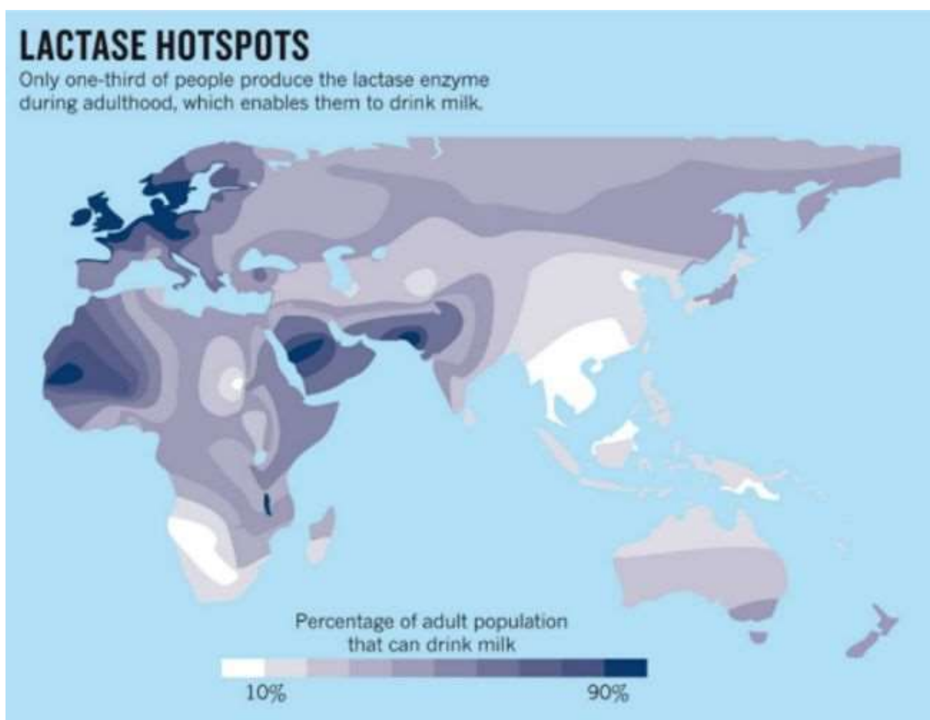
Obviously, lactose is consumed by mammals. It is also consumed by bacteria and fungi in the production of yogurt and cheeses (both of which we will explore), and it provides a fascinating case study of natural selection in humans. This case study has to do with lactose intolerance. Many adult mammals (humans as well as other furry, milk-producing organisms such as raccoons, apes, whales, tigers, bears, etc…) lack the ability to digest lactose (i.e., they are lactose intolerant) because they stop producing the enzyme lactase at adolescence. This makes perfect sense from an evolutionary perspective, because most mammals stop breast feeding at a young age. Lactose in the digestive systems of lactose intolerant individuals is digested by bacteria that produce gaseous wastes, and these cause gastrointestinal distress that manifests in many ways.

We looked at the following map of lactose intolerance. You should be able to explain, using the language of natural selection, the geographic patterns of lactose tolerance/intolerance in this map. (Red and brown are populations that in general do not produce lactase into adulthood. Green populations reflect the ability to digest lactose. (The red dots in USA and Australia indicate lactose intolerance among Native Americans and African Americans (USA) and Australian Aboriginals).



Here's another map (not shown in lecture) that might be easier to read.

What were humans doing in the "lactase hotspots" that leads to **lactase persistence** into adulthood in these locations? Again, explain in terms of natural selection.



<u>Polysaccharide</u><u>s</u>: large carbohydrates that are constructed of many monosaccharides. Polysaccharides are polymers constructed from monomers such as glucose (most typical) or other sugars.

Monomers: Small, individual units that can be linked together to form polymers.
Polymer: A large molecule constructed from many monomers.
(We will use the terms monomer/polymer to describe other biomolecules).

Polysaccharides serve two important functions:
1) long term storage of energy (sugar molecules)
2) provide physical structure of plant cells tissues

The are many types of **polysaccharides**, we will focus upon three (starch, cellulose, chitin):

Starch – Storage polysaccharide in plants. They are polymers of α-glucose bonded together at C atoms 1 and 4 (this bond is thus called an α-1,4 bond or α-1,4 linkage), thus forming long chains constructed from α-glucose monomers (<u>amylopectin</u> is slightly more complex, see below). Starch serves as a storage bank from which plants can remove glucose molecules for fuel.

<u>There are two forms of starch:</u>
Amylose - (<u>un</u>branched polymer of glucose monomers, as described above / in lecture)
Amylopectin - (<u>branched</u> polymer of glucose monomers). Amylopectin molecules have a backbone of α-glucose molecules (i.e., this backbone is amylose). In amylopectin, however, short branches of ~8-12 α-glucose monomers branch off the main chain approximately every 10-25 glucose monomers. These side branches are attached by their C1 atom to the C6 of glucose monomers in the main chain. (FYI: the term glucose 'residue' is sometimes used synonymously with 'monomer' in referring to polysaccharides – so be aware that you might see that in youtube tutorials etc.).

Glycogen - A storage polysaccharide in animals and fungi. Glycogen is structurally similar to amylopectin in that it is a branched polymer of glucose monomers, but there are many more side branches in glycogen than in amylopectin. This design provides glycogen with more terminal points ("ends" of chains) for amylase to act upon (we'll expand upon this point during our proteins lecture), thus increasing access to stored energy to fuel episodes of intense activity. [FYI: Glycogen is primarily stored in liver cells (up to 8% by weight, this glucose is available to throughout the body) and in the muscle cells (1-2% by weight, this glucose used in muscle tissue).]

Amylase – enzyme that catalyzes (i.e., causes or accelerates) hydrolysis of amylose into sugars (glucose and perhaps maltose). There are two types of amylase that we will explore in greater detail during our lecture on proteins (α-amylase and β-amylase).

Cellulose – Plant structural molecule. Cellulose is a primary building material in the cell walls of plant cells, and is the most abundant biomolecule on Earth. Cellulose molecules are constructed from long chains of β-glucose monomers bonded together at C atoms 1 and 4 (this bond is thus called a β-1,4 bond or β-1,4 linkage). Neighboring β-glucose monomers in a cellulose polymer are "upside down" relative to each other. Multiple polymers cross-link to each other via H bonds (formed between –OH groups), thus forming strong microfibrils.

Be able to draw a cellulose molecule, including the following detail:

- A single β-glucose ring monomer in complete atomic detail as we did in class, as a reference and in order to prove that you can. You can then work from this using "simplified" β-glucose ring monomers we drew in class.
- The "simplified" β-glucose ring monomers (an hexagon containing an O atom) linked together in a chain displaying the…:
- Correct orientation (i.e., "upside-downedness!") of neighboring β-glucose monomers in the cellulose polymer
- Two individual cellulose polymers H bonded together to form a microfibril – include the H bonds between neighboring polymers in the microfibril.

The β-1,4 bond in glucose is broken by an enzyme called cellulase. No animals produce cellulase (except, it is hotly debated, some species of termites…!) and therefore cellulose molecules can NOT be digested by ANY animals acting alone. Certain (but not all!) fungi, protists, and bacteria are the only organisms that produce the enzyme cellulase, and thus are capable of digesting cellulose. Thus, any animals that derive energy from cellulose do so by harboring microorganisms in their digestive system, and these microbes are capable of breaking the β-1,4 bond b/c they produce cellulase – that's how cows and termites do it!!

Cellulose is the most abundant biomolecule on Earth. The fibrils formed by cross-linked polymers make a very durable and structurally solid "cable-like" molecule. The fact that no animal can digest cellulose (without the aid of symbiotic bacteria, protists, or fungi) makes cellulose a long lasting, durable and abundant structural molecule. This is one reason plants use it to make cell walls. (Note: The debate rages on, as does current research, with regard to the extent to which termites might produce endogenous ["their own"] cellulase vs. how much they rely upon cellulase originating from protists in their digestive systems – this would make a great topic for a review paper…!).

Chitin – Structural polysaccharide found in cell walls of fungi. We won't talk about this in great detail until week 13-14 (if at all). This, no need to know the atomic detail of chitin molecules.

Enzymes: A Sinfully Brief Introduction

During lecture today, we introduced an important class of proteins called enzymes. We will elaborate on the proteins next week.

For today, I asked you to know the following about enzymes:

1) Enzymes are proteins that catalyze (accelerate or "make possible") chemical reactions.
2) Any one enzyme can catalyze one specific chemical reaction (many, many times!).
3) The names of enzymes end with the suffix "–ase".
4) The root word in the name of an enzyme often pertains to the molecule(s) upon which it acts to catalyze a chemical reaction (e.g., cellulase, lactase…)