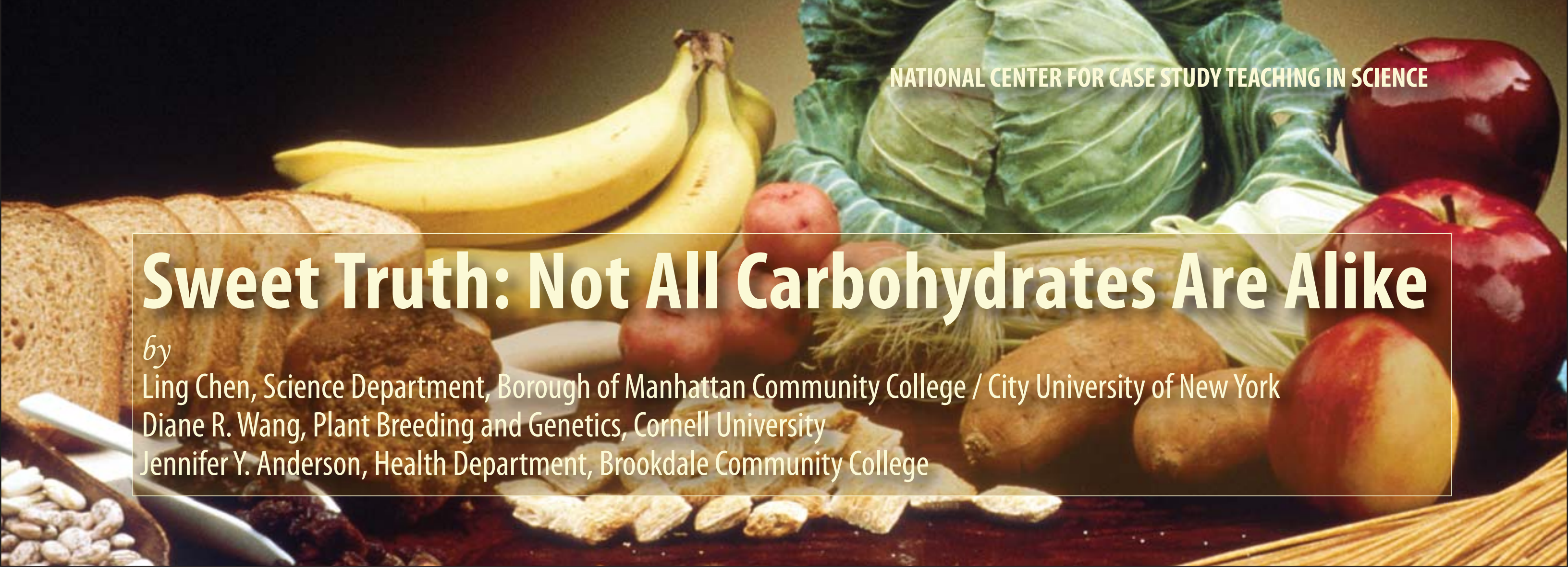

NATIONAL CENTER FOR CASE STUDY TEACHING IN SCIENCE

Sweet Truth: Not All Carbohydrates Are Alike

by
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This case study contrasts the structures of different pairs of simple and complex carbohydrates: D- and L-glucose, α- and β-D-glucose, lactose and sucrose, amylose and cellulose. The story also explains the similarity in symptoms related to the gastrointestinal bacteria fermentation of lactose and soluble fibers and compares the enzymes that are responsible for the breakdown of lactose, amylase, and cellulose. Finally, the health benefits of consuming both soluble and insoluble fibers are discussed.

Mike and Jack are best friends. They go to the same college, where they are roommates, and even share a few classes. They plan to see Professor Jaffy to review the math exam they took last week in hopes of digging out some extra points.

Mike: Jack, it's Professor Jaffy's office hour. We should leave now before it gets too crowded; I don't want to miss it this time.

Jack: Ugh, I'm afraid I'm going to have to pass. I'm having a bloating situation here. It would be too embarrassing if there were a gas leakage.

Mike: Are you kidding? I don't want to go alone.

Jack: I'm serious. Feels like some explosive reactions are happening inside of me. Probably too much fiber from lunch, and I don't want to be a laughing stock.

Mike: What in the world did you have?

Jack: A super-sized salad, two bowls of bean soup, and something healthy that I don't even remember. I was so hungry I just wolfed them down.

Mike: Well then, I'll go by myself. Do you have any questions for the professor?

Jack: I guess. You can ask her why veggies and beans are gas producers… just kidding! I know they both do wonders for our health. Who would have thought they'd be such a pain in the butt!

Mike: I hear you. I just did a research paper on fibers for my nutrition class. Plant fibers are beneficial to humans with moderation. Your bloating problem is because you increased your fiber consumption too fast.

Jack: Tell me about it.

Mike: About one third of plant matter is made of cellulose, a polysaccharide (complex carbohydrate) that consists of several hundred to ten thousand glucose units. Glucose is a monosaccharide, or simple carbohydrate, also known as blood sugar. All glucose in cellulose is linked together by β-glycosidic bonds; therefore, such glucose is called β-glucose. However, the human digestive system lacks cellulase, an enzyme, to cleave the linking bond. Because of that humans can't make use of the glucose in the fibers.

Jack: But I know for a fact that horses and cows can feed on cellulose. That must mean they have the necessary enzyme to break down the glycosidic bonds of cellulose.

Mike: Actually, the reason that herbivores are capable of digesting cellulose is the presence of some microorganisms in their stomach that contain cellulase.

Jack: Really? I didn't know those animals can live off grass because of those microorganisms. That's interesting!

Mike: Yup, it's called symbiosis. Humans don't have the same enzymes as microorganisms do. Instead, we have amylase, an enzyme which breaks α-type bonds (α-1, 4- and α-1, 6-glycosidic bonds) found in starch, a polysaccharide, to release the glucose.

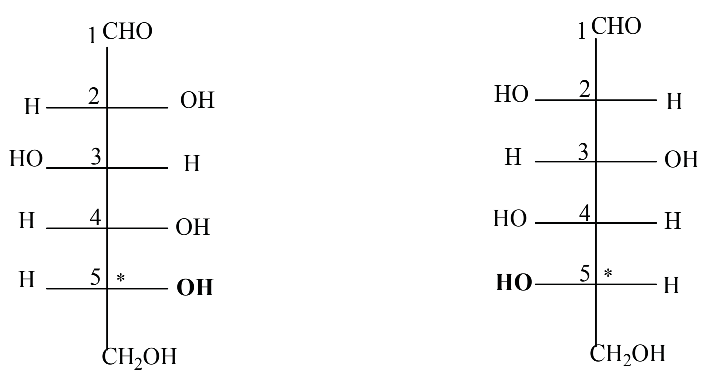
Jack: If I heard you correctly, glucose is a monomer, or the building block for both cellulose and starch. The major structural difference between these two polysaccharides is the connecting bond—α-kind of connection in starch and β-kind in cellulose.

Mike: Nice summary!

Jack: But I don't really know what you meant by α- and β-type bonds.

Mike: Ok, let me draw out the structures to illustrate the ideas briefly (Figure 1). There are two types of glucose: D-glucose and L-glucose. In Fischer projection, the carbon chain of the glucose is placed vertically with the aldehyde group at top, known as C-1. If the hydroxyl group (-OH) attaching to C-5 (the very last chiral carbon, marked with an asterisk) is found on the right side, it's designated as D-glucose; while in L-glucose, the –OH attaches to the left side of the C-5. These two glucose structures are like our hands, one sugar is the left-hand version and the other the right-hand version.

Figure 1. Fischer projections of D-glucose and L-glucose.



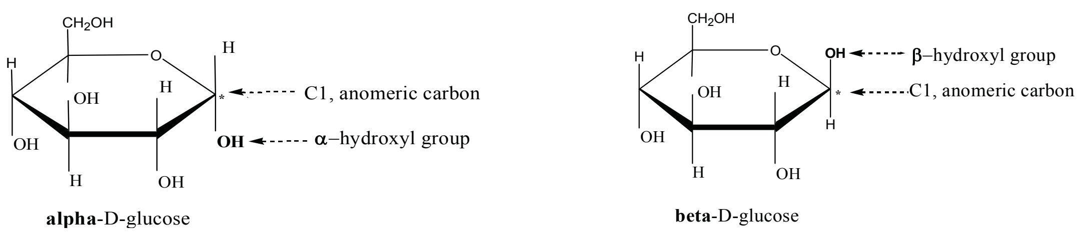
Jack: I see. So, D-glucose and L-glucose are different compounds.

Mike: Yes, they're stereo isomers (or enantiomers) and mirror images of each other with different optical activities. D-isomers of sugars are commonly found in nature. From now on let's only deal with the D-type of sugars.

Jack: Sure. What about the bonding difference between α-type and β-type?

Mike: α and β are two different anomers according to stereochemistry. The difference between the two is the orientation of the hydroxyl group (–OH). It attaches to the first carbon, C-1, in cyclic structures. C-1, anomeric carbon, is a new chiral carbon created by the ring formation and can be found at the rightmost corner of the Haworth structure. Look (at the star-labeled carbons in Figure 2), the –OH is in down position in α-D-glucose; but in β–D-glucose, the –OH is in upward projection.

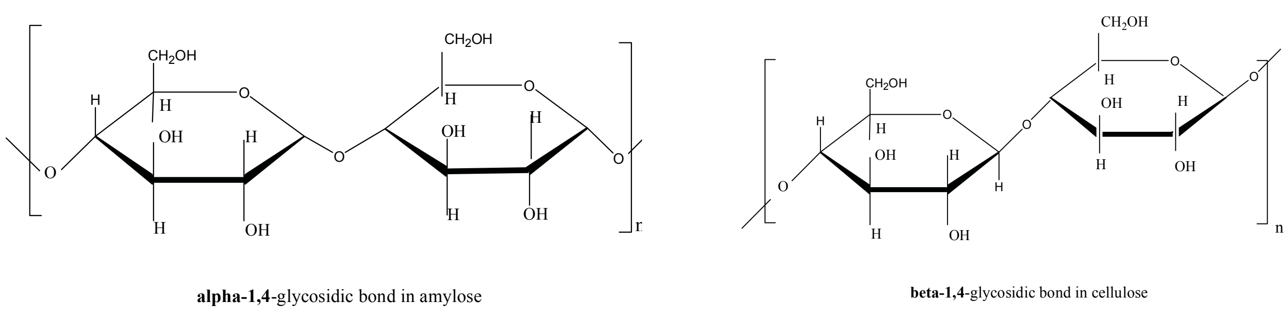
Figure 2. Haworth structures of α-D-glucose and β-D-glucose.



Jack: Is that all? The only difference of glucose in cellulose and starch is due to the projection of the –OH at C-1 position? It sounds so simple! Does the subtle difference explain why cellulose provides strong supportive strength and rigidity for plants, for instance, trees, whereas starch, found in mashed potatoes, does not?

Mike: Absolutely. α-1,4-glycosidic bonds make starches more relaxed with a coiled or helical structure. β-1,4-glycocidic bonds make cellulose linear to provide an extended structure (see Figure 3). As a result, several cellulose molecules can parallel and cross-link with each other to form microfibrils; together, these cellulose molecules can support trees as tall as several hundred feet! Unfortunately, humans can't digest the cellulose or fibers. That's why, even if we were really hungry, we can't eat bamboo like a giant panda or cotton clothing.

Figure 3. Comparisions of α-1,4-glycosidic bond with β-1,4-glycosidic bond. α-maltose and β-cellobiose are the repeating disaccharides in amylose and cellulose, respectively.



Jack: I know that! In what form does glucose exist when it dissolves in water?

Mike: In solution, all three forms coexist in equilibrium: α- and β-ring structures, and the open chain structure. The α-form can convert to the β-form, and vice versa, through a trace amount of the open-chain structure.

Jack: Ok, as long as the proper enzyme is present, glucose can be released from both starch and cellulose. Well, since humans cannot use plant fibers, what's so great about them? I'm so fed up with fibers now.

Mike: There are two kinds of fibers from plants, depending on the solubility in water: soluble and insoluble. Though fibers are carbohydrates, they are metabolically inert to humans.

Jack: Aha, they're called fibers because they're indigestible polymers! It's a light-bulb moment of mine, ding!

Mike: However, those fibers influence the absorption of materials like nutrients and toxins. The insoluble fiber such as cellulose goes through our gastrointestinal tracts directly. In the passing process, the insoluble fibers absorb water and swell to make the stool soft and loose, and thereby shortening the transit time. Besides, the bulky hydrated fiber molecules also serve as brushes to scrub the GI tract. They're the cleaning crews of the guts.

Jack: That explains why consuming insoluble fibers can help prevent constipation, diverticulosis (little pouches protruding from outer colon walls), and even colon cancer. The insoluble fibers scrub and cleanse the GI tract, and facilitate normal bowel movement. As a result, the toxins can be eliminated promptly. Tell me about the soluble fibers. Are they also good for our bodies?

Mike: Definitely! Consumption of soluble fibers has shown to help prevent heart disease by reducing the absorption of fatty substances such as cholesterols.

Jack: What are soluble fibers made of?

Mike: Pectin, for example, is a polysaccharide that contains molecules of α-1,4-D-galactosyluronic acid. Pectin is found in and between plant cell walls. It has low molecular weight compared to cellulose, which makes pectin more soluble in water.

Jack: My cholesterol level is through the roof. I really need some help to bring it down. That's why I tried to eat healthy. How does it work?

Mike: In the GI-tract, soluble fibers absorb water and form a gel-like suspension to trap fats; as a result, they inhibit the absorption of fats in its path.

Jack: A gel suspension, like a jelly? Is it the same stuff that slows down the digestion of carbohydrates to prevent a rapid up-swing of the blood sugar level after meals?

Mike: That's right. Pectin is often used as a gelling agent to make jams. Pectin forms a net to tangle up cholesterols, fats, and other carbohydrates.

Jack: A perfect trapping system at work. That's so cool.

Mike: It sure is. Soluble fibers are often called prebiotics and are available over the counter as a dietary supplement.

Jack: (Sound of passing gas.) Excuse me. It all sounds good. But where does the gas come from?

Mike: The gases are produced when the bacteria in the colon makes a meal of the soluble fibers and other undigested material. The bacteria basically have a party feeding on leftovers; the gasses are the byproducts of the fermentation process.

Jack: That's the price we have to pay. Next time I will really have to think twice before eating beans or raw veggies before any social events.

Mike: Don't be discouraged. Pre-soaking beans overnight can remove some soluble fibers from the outer coating of the beans and help reduce gas production. Remember, moderation is the key.

Jack: I learned my lesson. Is the fermentation the same reason for lactose intolerance?

Mike: Pretty much so. Passing gasses is also one of the symptoms in lactose intolerance but the undigested food is lactose;

the missing enzyme is lactase. Lactose is a disaccharide, simple carbohydrate, found in milk or dairy products so it's called milk sugar. Lactose consists of two different monosaccharides, a galactose and a glucose, via β-1,4-glycosidic bond. Without lactase, the ingested lactose can't be broken down; in turn, it feeds bacteria in the GI tract and causes flatulence.

Jack: Aha, the gut bacteria again. So, lactose intolerance is a similar gassy situation to mine; except it's caused by a lack of lactase to hydrolyze the milk sugar. That explains why it's necessary to add lactase to milk in order to pre-digest lactose for someone who is lactose intolerant to be able to consume dairy products. Are there other examples of disaccharide?

Mike: Table sugar is called sucrose, also a disaccharide that is made of glucose and fructose.

Jack: I know fructose, or fruit sugar, is the sweetest carbohydrate. What kind of bond links the two sugar units together?

Mike: Ha, now you're thinking like a chemist. The two sugars are linked by α, β-1, 2-glycosidic bond.

Jack: Interesting, the disaccharides we're talking about have different sugar components that are connected by different bonds. How about sugar substitutes?

Mike: The only one I came across in my research is the reduced version of glucose, sorbitol, which is another kind of monosaccharide known as sugar alcohol.

Jack: Ah, sorbitol is a reduced glucose; it tastes sweet but doesn't have much caloric value. So, sorbitol is used as a sugar substitute in sugar-free food for people who are diabetics or on a diet. Sounds like a perfect sweetener.

Mike: Not so fast. Sorbitol can cause bloating, diarrhea, gas, and cataracts in some people when consumed in excess amounts.

Jack: Whew, I certainly don't need that. I bet the gut bacteria have a hand in those irritable bowel symptoms, but the cataracts seem out of the blue.

Mike: Why don't you look it up? Oh, it's late; I'd better get going before the office hour is over.

Jack: Wait! I actually feel much better now; I don't want to miss it either.

Mike: Sweet. Let's go.

Questions

1. In aqueous solutions there are three forms of glucose: the α-form (36%), the β-form (64%) and a trace amount of the open-chain form. At equilibrium, the alpha and beta cyclic forms are interconverted by way of the open-chain structure. Explain (a) why the cyclic forms exist predominately in solutions, and (b) why the β-form is more abundant than the α-form.
2. Name the monosaccharides and disaccharides in amylose and cellulose. Compare the structural and conformation differences between amylose and cellulose. A simple iodine test can be used to distinguish the two polysaccharides. Describe the iodine test and explain the observation.
3. Write the reduction reaction of glucose to form sorbitol. List and explain the side effects caused by too much sorbitol consumption.
4. Blood sugar levels can be detected by test strips, which are coated with glucose oxidase and an indicator. Write the oxidation reaction of glucose that happens in the testing process.
5. Why are soluble fibers identified as prebiotics?

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