Carbohydrates
Role of sugars in foods
<table>
<thead>
<tr>
<th>Product</th>
<th>Total Sugar (%)</th>
<th>Mono- and Disaccharides (%)</th>
<th>Polysaccharides (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fruits</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Apple</td>
<td>14.5</td>
<td>glucose 1.17; fructose 6.04; sucrose 3.78; mannose trace</td>
<td>starch 1.5; cellulose 1.0</td>
</tr>
<tr>
<td>Grape</td>
<td>17.3</td>
<td>glucose 5.35; fructose 5.33; sucrose 1.32; mannose 2.19</td>
<td>cellulose 0.6</td>
</tr>
<tr>
<td>Strawberry</td>
<td>8.4</td>
<td>glucose 2.09; fructose 2.40; sucrose 1.03; mannose 0.07</td>
<td>cellulose 1.3</td>
</tr>
<tr>
<td>Vegetables</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Carrot</td>
<td>9.7</td>
<td>glucose 0.85; fructose 0.85; sucrose 4.25</td>
<td>starch 7.8; cellulose 1.0</td>
</tr>
<tr>
<td>Onion</td>
<td>8.7</td>
<td>glucose 2.07; fructose 1.09; sucrose 0.89</td>
<td>cellulose 0.71</td>
</tr>
<tr>
<td>Peanuts</td>
<td>18.6</td>
<td>sucrose 4–12</td>
<td>cellulose 2.4</td>
</tr>
<tr>
<td>Potato</td>
<td>17.1</td>
<td></td>
<td>starch 14; cellulose 0.5</td>
</tr>
<tr>
<td>Sweet corn</td>
<td>22.1</td>
<td>sucrose 12–17</td>
<td>cellulose 0.7; cellulose 60</td>
</tr>
<tr>
<td>Sweet potato</td>
<td>26.3</td>
<td>glucose 0.87; sucrose 2–3</td>
<td>starch 14.65; cellulose 0.7</td>
</tr>
<tr>
<td>Turnip</td>
<td>6.6</td>
<td>glucose 1.5; fructose 1.18; sucrose 0.42</td>
<td>cellulose 0.9</td>
</tr>
<tr>
<td>Others</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Honey</td>
<td>82.3</td>
<td>glucose 28–35; fructose 34–41; sucrose 1–5</td>
<td></td>
</tr>
<tr>
<td>Maple syrup</td>
<td>65.5</td>
<td>sucrose 58.2–65.5; hexoses 0.0–7.9</td>
<td></td>
</tr>
<tr>
<td>Meat</td>
<td></td>
<td>glucose 0.01</td>
<td>glycogen 0.10</td>
</tr>
<tr>
<td>Milk</td>
<td>4.9</td>
<td>lactose 4.9</td>
<td></td>
</tr>
<tr>
<td>Sugarbeet</td>
<td>18–20</td>
<td>sucrose 18–20</td>
<td></td>
</tr>
<tr>
<td>Sugar cane juice</td>
<td>14–28</td>
<td>glucose + fructose 4–8; sucrose 10–20</td>
<td></td>
</tr>
</tbody>
</table>
Role of sugars in foods

- Sweetness
- Browning
- Fermentation substrate
- Separating agent – prevent lump formation in starch gels
- Reduce starch gelatinization
- Dehydrate pectin- permit gel formation in jelly
- Aerate batter and dough
- Weaken gluten structure (compete with glutenin and gliadin for water) increase tenderness
- Moisture retention in baked products
• Stabilize egg white foams
• Raise coagulation temperature of protein
• Add bulk and body to foods (yogurt)
• Slow crystallization in candies or syrups that are made with corn sweetener or hydrolyzed sucrose (invert syrup)
• Monosaccharides – glucose, fructose
  – Free carbonyl group – reducing sugars and participate in browning reactions (Maillard rxn w/protein)
  – Carmelization reactions – decomposition at high temperature
  – Contribute body and mouthfeel to foods (more viscous). Must modify viscosity for foods with non-nutritive sweetner
  – Fermentation
  – Preservative – at high levels (Aw <0.85)
Fischer aldehydo-D Glucose
\[\xrightarrow{\text{Glucopyranose}}\]
\[\xrightarrow{\text{Conformational}}\]
GLUCOSE (dextrose)
Aldose (aldohexose)
Fischer keto-\(\text{D}\)-Fructose

\[\begin{align*}
\text{Fructose} & \quad \text{Fructopyranose} \\
\text{Fructofuranose} & \quad \text{Absorbin} \\
\text{Hexulopyranose} & \quad \text{C1-\(\text{D}\)}
\end{align*}\]

FRUCTOSE (levulose)
Ketose (2-ketohexose, 2-hexulose)
– Disaccharides – sucrose, maltose, cellobiose
<table>
<thead>
<tr>
<th>Oligosaccharide</th>
<th>Chemical Structure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sucrose</td>
<td>(α-D-glucopyranosyl β-D-fructofuranoside)</td>
</tr>
<tr>
<td>Lactose</td>
<td>(4-O-β-D-galactopyranosyl-D-glucopyranose)</td>
</tr>
<tr>
<td>Maltose</td>
<td>(4-O-α-D-glucopyranosyl-D-glucopyranose)</td>
</tr>
<tr>
<td>α,α-Trehalose</td>
<td>(α-D-glucopyranosyl–α-D-glycopyranoside)</td>
</tr>
<tr>
<td>Raffinose</td>
<td>[O-α-D-galactopyranosyl-(1→6)-O-α-D-glucopyranosyl-(1→2)-β-D-fructofuranoside]</td>
</tr>
<tr>
<td>Stachyose</td>
<td>[O-α-D-galactopyranosyl-(1→6)-O-α-D-galactopyranosyl-(1→6)-O-α-D-glucopyranosyl-(1→2)-β-D-fructofuranoside]</td>
</tr>
<tr>
<td>Verbascose</td>
<td>[O-α-D-galactopyranosyl-(1→6)-O-α-D-galactopyranosyl-(1→6)-O-α-D-glucopyranosyl-(1→2)-β-D-fructofuranoside]</td>
</tr>
</tbody>
</table>

Figure 4-9 Composition of Some Major Oligosaccharides Occurring in Foods. Source: From R.S. Shallenberger and G.G. Birch, Sugar Chemistry, 1975, AVI Publishing Co.
Sugar Alcohols

• Carbonyl group -> OH.

• Sweet but less than sucrose. Not easily fermented (non cariogenic)

• 1-3Kcal/g

• Low energy bulk ingredient in place of sugar

• Sorbitol – transformed as fructose (diabetic products)
xylitol

sorbitol
<table>
<thead>
<tr>
<th>Polyol</th>
<th>Sugar Component</th>
<th>Cal/g</th>
<th>Comments/Applications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maltitol</td>
<td>Maltose</td>
<td>2.1</td>
<td>Chocolates</td>
</tr>
<tr>
<td>Mannitol</td>
<td>Mannose</td>
<td>1.6</td>
<td>Bulking agent in powdered products; chewing gum (anti-cariogenic)</td>
</tr>
<tr>
<td>Sorbitol</td>
<td>Sorbose</td>
<td>2.6</td>
<td>Metabolized by fructose-1-phosphate pathway (needs no insulin)/baked goods, beverages</td>
</tr>
<tr>
<td>Xylitol</td>
<td>Xylose</td>
<td>2.4</td>
<td>Cooling mouthfeel/chewing gum (anti-cariogenic)</td>
</tr>
</tbody>
</table>
Table 4-2 Occurrence of Sugar-Alcohols in Some Foods (Expressed as mg/100g of Dry Food)

<table>
<thead>
<tr>
<th>Product</th>
<th>Arabinol</th>
<th>Xylitol</th>
<th>Mannitol</th>
<th>Sorbitol</th>
<th>Galactitol</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bananas</td>
<td>—</td>
<td>21</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Pears</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>4600</td>
<td>—</td>
</tr>
<tr>
<td>Raspberries</td>
<td>—</td>
<td>268</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Strawberries</td>
<td>—</td>
<td>362</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Peaches</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>960</td>
<td>—</td>
</tr>
<tr>
<td>Celery</td>
<td>—</td>
<td>—</td>
<td>4050</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Cauliflower</td>
<td>—</td>
<td>300</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>White mushrooms</td>
<td>340</td>
<td>128</td>
<td>476</td>
<td>—</td>
<td>48</td>
</tr>
</tbody>
</table>

Artificial Sweeteners

• Acesulfame K - no bitter aftertaste. 200x sucrose. Sunette®


• Saccharin - Me anthranilate. Naturally found in grapes. 300-700x sucrose. Requires labeling. Sweet-n-Low®
Artificial Sweeteners

• Sucralose. Trichloro-derivative of sucrose. 400-800x sucrose. Measures cup for cup like sucrose. Stable over wide pH, T range. Splenda® Cyclamate. Banned in 1970. 30x sucrose. Canada

• Stevioside. Glycoside 300x

• Thaumatin – peptide. 2000-3000x. Talin®
Table 8.1 Relative Sweetness of Selected Sugar Solutions (5%) and Other sweeteners

<table>
<thead>
<tr>
<th>Sweetener</th>
<th>Relative Sweetness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thaumatin(^b) (Talin™)</td>
<td>2000–3000</td>
</tr>
<tr>
<td>Monellin(^b)</td>
<td>1500–2000</td>
</tr>
<tr>
<td>Sucralose(^b) (Splenda®)</td>
<td>5–2000</td>
</tr>
<tr>
<td>Stevioside(^b)</td>
<td>300</td>
</tr>
<tr>
<td>Saccharin(^b)</td>
<td>200–300</td>
</tr>
<tr>
<td>Acesulfame K(^b) (Sunette®)</td>
<td>130–200</td>
</tr>
<tr>
<td>Aspartame(^b) (Nutrasweet®, Equal®)</td>
<td>100–200</td>
</tr>
<tr>
<td>Cyclamates(^b)</td>
<td>30–80</td>
</tr>
<tr>
<td>Fructose</td>
<td>1.3(^c)</td>
</tr>
<tr>
<td>Xylitol(^b)</td>
<td>1.01</td>
</tr>
<tr>
<td>Sucrose</td>
<td>1.0(^d)</td>
</tr>
<tr>
<td>Tagatose (Naturlose™)</td>
<td>0.92</td>
</tr>
<tr>
<td>Invert sugar</td>
<td>0.85–1</td>
</tr>
<tr>
<td>Xylose</td>
<td>0.59</td>
</tr>
<tr>
<td>Glucose</td>
<td>0.56</td>
</tr>
<tr>
<td>Galactose</td>
<td>0.4–0.6</td>
</tr>
<tr>
<td>Maltose</td>
<td>0.3–0.5</td>
</tr>
<tr>
<td>Lactose</td>
<td>0.2–0.3</td>
</tr>
</tbody>
</table>


\(^b\)Nonsugar sweetener.

\(^c\)Highly variable, depending on temperature. This is a representative value, but measurements may range from 0.8 to 1.7.

\(^d\)Value of sucrose arbitrarily set at 1.0 for reference purposes.
Polysaccharides

- Polysaccharides
- Starch
- Gums (plant, microbial)
- Cellulose (modified)
- Dietary fiber
Polysaccharides – Glucose polymers

- Dextrin-intermediate length linear glucose polymers ($\alpha$-1,4). Starch hydrolysis.
- Maltodextrin – fat replacers - similar mouthfeel as fat
- Dextran-(\(\alpha \) -1,6). Produced by fermentation.
Polysaccharides – Glucose polymers

• Starch-
  – amylose linear glucose polymer ($\alpha$-1,4) and
  – amylopectin – branched glucose polymer ($\alpha$-1,4 & $\alpha$-1,6 (branch point each 15-30 glucose). Very large ‘tree shaped’ molecule. Less soluble than amylose
  – Forms gels – corn, wheat
  – Does not form gels – waxy maize, tapioca
Polysaccharides

- Pectins – plant cell wall material. Polymer of $\alpha$-D-galacturonic acid. Water soluble, gelling agents
- Gums – stabilizers and thickeners
  - terrestrial (arabic, tragacanth, guar, locust bean)
  - marine plant (carrageenan, alginate, agar) Alginate form gels (calcium bridges).
  - Microbial (xanthan, gellan, dextran, curdlan)
  - Synthetic - microcrystalline cellulose, cellulose, methyl cellulose, carboxymethyl cellulose
Starch- Picking one

- Thickening or gel forming ability
- Mouthfeel (gummy, stringy)
- Freeze-thaw stability- (waxy or crosslinked starch)
Starch properties- Controlling gelatinization

- **Acid**- hydrolyzes starch. Less water absorption -Less firm cooled product. Add acid (lemon juice for filling – at end of cooking process)

- **Agitation**- aids in independent swelling of starch granules. More uniform paste. Less lumps. Excessive stirring will rupture granules and lead to thin, opaque pasty mixture
Starch properties- Controlling gelatinization

• **Enzymes**
  ✓ $\alpha$–amylase (intentionally added – random hydrolysis), limit retrogradation (formation of crystalline form when cooled)
  ✓ $\beta$-amylase (produces maltose (malting barley), germinating wheat

• **Fats and protein**- coat (fat), adsorbs (protein) to surface of starch granule. Delays hydration and increase in viscosity. Fat used as separating agent for flakey pie crusts
Starch properties- Controlling gelatinization

• Sugar
  – decrease firmness of cooked and cooled starch product.
  – Absorbs water that granule would have absorbed
  – Delays absorption - preventing complete swelling of starch granule
  – Separating agent – allows individual swelling of granules
  – Increases gelatinization temperature.
  – Reduces hydrolytic affect of acid on starch hydrolysis
Modified Starch

- Thin boiling- hydrolyzed, very thin as hot liquid easy to pump. Form strong gels when formed (fewer branches, easier to form H bonds)
- Oxidized-sodium hypochlorite – softer gels than acid hydrolyzed
- Crosslinked-alter OH groups to reduce retrogradation (OH ethyl on C2). More stable to heat and agitation than native starch.
- “Resistant” starch – not digestable (chemically modified or repolymerized). Dietary fiber source that has functional properties of starch
Pectins

- Pectin—galacturonic acid polymer. Dispersible in water. Variable degree of methyl esters
- Low methoxy pectin—mostly free carboxyl groups. 20-40% methylated. Forms gels by crosslinking with Ca.
- High methoxy pectin—50-58% esterified. Forms gels with addition of acid and sugar. pH <3.5 for gel formation. Align at junction zones and form crosslinks.
Gums and hydrocolloids

- Complex branched hydrophilic heteroglycans. 1000DP
- Galactose (little or no glucose)
- Viscous solutions rather than gels
Functions of gums in food

• Thickeners- salad dressing, sauces, soups, beverages
• Stabilizer-ice cream, icing, emulsions
• Control crystal size- candy
• Suspending agent-salad dressing
• Gelling agents-fruit pieces, cheese analogs
• Coating agents- batters (fried foods)
• Fat replacers- low-fat salad dressings, ice cream, desserts
• Bulking agent-low fat foods
• Source of dietary fiber-beverages, soups, baked goods
Seed Gums

• Guar gum-contains only mannose/galactose 2:1. Soluble in cold water. Won’t gel alone. Forms gels with carrageenan and locust. Dressings, soups, sauces ice cream crystal inhibitor. Inhibits digestion and absorption of glucose.

• Locust bean - mannose/galactose 4:1. soluble only in hot water. Stabilizer in meat and dairy products. Gels with xanthan.
Plant Exudate Gums

  - Stabilize emulsions and control crystal size
- Tragacanth- very viscous sols. Impart creamy texture, suspend particles
Microbial Gums

- Xanthan- viscous sols stable over wide range of pH and T
- Thickener, stabilizer and suspending agent
- Forms gel with locust bean gum.
- Shear thins
Marine polysaccharides- Carrageenan

- Stabilize milk products (ice cream, process cheese, chocolate milk)

- (-)Galactose polymer with varying amount of (-) sulfate esters: Kappa (lowest sulfate), iota, lambda (highest sulfate) fractions. These generally used in combination

- Kappa -forms strong gels with K+
- Iota-forms strong gels with Ca++
- Lambda- too highly charged to gel
- Crosslinks with other gums
Marine polysaccharides- Agar

- Red algae. Galactose (a,b) polymer
- 2 fractions- agarose and agaroproctin (sulfate esters)
- Strong, transparent, heat-reversible gels
- Meat products and gels
Marine polysaccharides- Alginates

- Brown algae
- Mannuronic and guluronic acids
- Gel with Ca++
- Fruit purees, “synthetic fruit” and vegetable pieces, kosher caviar, candies
Synthetic Gums- Cellulose Derivatives

Glucose polymer, 3000+DP

Microcrystalline - Acid hydrolysis of cellulose. Bulking agent.

Methyl (MC) and carboxymethyl (CMC) cellulose – alkaline hydrolysis.

CMC- binder, thickener (fillings, puddings). Retard ice crystal and sugar crystal growth

MC- will gel when cooled

Hydroxypropyl, hydroxypropylmethyl cellulose – coatings for fried food (moisture migration)
Dietary Fiber

- **Structural polysaccharides**
  - Cellulose - B-D-glucose polymer
  - Hemicellulose - heteropolysaccharides of xylose, mannose, galactose
  - Pectins
- **Structural non-polysaccharides** - Lignin
- **Nonstructural polysaccharides**
  - Pentosans - polymers of arabinose and xylose (other sugars)
  - Gums