Sweeteners
What is sweetness?

- Sweetness consists of atomic figures that are rounded and not too small: wherefore it softens the body by its gentle action and unhesitatingly makes its way throughout. Yet it disturbs the other savors, for it slips in among the other atomic figures and leads them from their accustomed ways and moistens them.

Theophrastus, 2000 years ago
Why look for alternative sweeteners

- **Obesity**
  - A risk factor for coronary heart disease
  - CDC says obesity related medical expenditures were about $75 billion in 2003

- **Diabetes**
  - Need to control blood glucose levels

- **Dental caries (tooth decay)**
  - US dental bill is approximately 91.5 billion dollars annually (2006)
  - Of that, half ($45,750,000,000) is used just to repair tooth decay
General problem

- Over the last 90 years there has been a general shift in consumption away from complex carbohydrates (starch, fiber) toward simple carbohydrates (sugars, syrups)
Per capita consumption of carbohydrates

1910
Starch 68%
Sugar 32%

1980
Starch 47%
Sugar 53%

2008
Starch 52%
Sugar 48%
## Estimated per capita consumption of soft drinks

<table>
<thead>
<tr>
<th>Year</th>
<th>12 oz. Containers/yr</th>
</tr>
</thead>
<tbody>
<tr>
<td>1909</td>
<td>11</td>
</tr>
<tr>
<td>1950</td>
<td>105</td>
</tr>
<tr>
<td>1960</td>
<td>128</td>
</tr>
<tr>
<td>1970</td>
<td>242</td>
</tr>
<tr>
<td>1980</td>
<td>410</td>
</tr>
</tbody>
</table>
Annual soft drink production per capita in the U.S.
Nutritive sweeteners

- Impart sweet taste and calories
  - Sucrose
  - Fructose
  - Glucose
  - Honey
  - Molasses
  - Sugar alcohols
  - Maltodextrins
  - Neosugar
  - Aspartame
Nutritive sweetener properties

- Sweetness
- Body (viscosity) in beverages
- Bulk
- Desirable texture and mouthfeel
- Water binding
- Decrease freezing point of solutions
- Participate in Maillard browning
- Food source in fermentation
- Decrease sour or bitter flavors
## Selected relative sweetness values

<table>
<thead>
<tr>
<th>Carbohydrate</th>
<th>Relative Sweetness</th>
</tr>
</thead>
<tbody>
<tr>
<td>D-Fructose</td>
<td>140</td>
</tr>
<tr>
<td>Invert sugar</td>
<td>&gt;100</td>
</tr>
<tr>
<td>Sucrose</td>
<td>100</td>
</tr>
<tr>
<td>D-Glucose</td>
<td>70-80</td>
</tr>
<tr>
<td>Maltose</td>
<td>30-50</td>
</tr>
<tr>
<td>Lactose</td>
<td>20</td>
</tr>
</tbody>
</table>

See also W&B, Table 17.1
Actual sweetness

- Relative sweetness is determined in tap or distilled water by a sensory panel and is a relatively good guide in predicting sweetness.
- However, in real life, sweetness is application dependent.
Temporal considerations and sweetness

![Graph showing sweetness intensity over time for Fructose, Glucose, and Sucrose.](image)
New sweetener requirements

- Be safe for human consumption
- Have a sucrose-like taste
- Be water soluble (to match a 10-12% sucrose sweetness) and be fairly stable (to heat, light, pH)
- Be at least equal to sucrose on a cost per sweetness basis
Paracelsus (1493-1541)

- All substances are poisons, there is none which is not a poison. The right dose differentiates a poison and a remedy.
The Delaney Clause

No additive shall be deemed to be safe if it is found to induce cancer when ingested by man or animal or if it is found, after tests which are appropriate for the evaluation of food additives, to induce cancer in man or animal.
Sweeteners

- Carbohydrate
  - Natural
    - Sucrose
  - Synthetic
    - Trichlorogalactosucrose
    - L-Sugars
## Sweeteners (cont.)

### Non-carbohydrate

- **Natural**
  - Monellin
  - Thaumatin
  - Glycyrrizin
  - Stevia

- **Synthetic**
  - Saccharin
  - Cyclamate
  - Aspartame
  - Neotame
  - Acesulfame
Shallenberger’s’s AH/B
Kier’s X

X is a hydrophobic group.

This helps explain the **intense sweetness** of some compounds.
Non-nutritive sweeteners

- Generally, these are high intensity sweeteners and contribute only sweetness to the foods to which they are added.
- Little contribution to
  - Bulk
  - Maillard browning
  - Solution viscosity (mouthfeel)
Saccharin
Saccharin

- Discovered by Remsen and Fahlberg (Johns Hopkins) - 1879

- Sweetness = 300-400x (bitter or metallic aftertaste)
Saccharin

- Regulatory history
  - Discovered - 1879
  - Generally used and considered safe since the early 1900’s
  - Feeding experiments suspicious - 1970’s
    - Rat bladder tumors
  - FDA proposes ban - 1977
  - Congressional moratorium on ban - 1977 to 1996
  - FDA tells Congress it no longer intends to ban saccharin
<table>
<thead>
<tr>
<th>Suspected carcinogen</th>
<th>Foods of concern</th>
<th>Food intake to match dose levels in animal tests</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cyclamates and/or saccharin</td>
<td>Artificially sweetened soft drinks</td>
<td>138-552 bottles per day (cyclamate)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>875 bottles per day (saccharin)</td>
</tr>
</tbody>
</table>
Cyclamate

\[
\text{Cyclamate} \quad \text{SO}_3^- \text{Na}^+ 
\]
Cyclamate

- Discovered by Michael Sveda (1912-1999) at the University of Illinois - 1937

- Sweetness - 30-60x (but no aftertaste)
Cyclamate

- Regulatory history
  - Discovered - 1937
  - Began food use - early 1950’s
  - Feeding experiments suspicious - late 1960’s
  - FDA ban - 1970
  - Much additional testing has suggested that cyclamate is not carcinogenic
  - FDA has been reconsidering its ban
Cyclamate

- Safety considerations
  - Food intake to match levels in animal tests = 138-552 12 oz. bottles per day
- Sucaryl: 9 parts cyclamate and 1 part saccharin
Aspartame

Phenylalanine

Aspartic acid

Methanol

Aspartame
Aspartame

- Discovered by Schlatter at G. D. Searle - 1965
- Structural considerations
  - Neither phenylalanine nor aspartic acid is sweet by itself
  - Removal of the methyl ester destroys sweetness
- Sweetness = 180-200x
Aspartame

- Safety considerations
  - PKU
  - Effect on neurotransmitters - Wurtman
  - Methanol - Monte
Neotame

Phenylalanine

Aspartic acid

Methyl ester

Neohexyl group
Neotame

- Approved July 5, 2002
- Uses
  - Baked goods, non-alcoholic beverages, chewing gum, confections and frostings, frozen desserts, gelatins and puddings, jams and jellies, processed fruits and fruit juices, toppings and syrups
Neotame

- Relative sweetness = 7000-13,000x sugar, depending on the food application
- Water soluble
- White crystalline powder
- Heat stable so it can be used in baking applications (unlike Equal)
- Enhances or extends other sweeteners and tastes, especially mint
Neotame

- Quickly metabolized and eliminated from the body via normal biological processes
- FDA reviewed data from more than 113 animal and human studies designed to identify toxic effects such as cancer-causing, reproductive, and neurological effects and concluded that neotame is safe for consumption
Advantame

3-hydroxy-4-methoxy phenyl moiety

Aspartic acid

Phenylalanine

Methyl ester
Advantame

- Approved May 19, 2014
- Most recently approved alternative sweetener
- A derivative of aspartame
- 20,000 x sweeter than sucrose
- Clean sucrose-like taste
- Approved for general use in foods and beverages
- Also, a flavor enhancer
Advantame

- Available in 3 forms
  - Pure advantame
  - VM95-5% advantame + 95% maltodextrin
  - VM99-1% advantame + 99% maltodextrin
Advantame-safety

- FDA reviewed data from 37 animal and human studies.
- The safety studies were designed to identify possible toxic effects, such as reproductive, neurological, and cancer-causing effects.
- The FDA concluded after a thorough evaluation that advantame is safe for human consumption under the petitioned conditions of use.
Acesulfame
Acesulfame

- Discovered by Claus and Jensen (Hoechst) - 1967
- Commercial name - Sunette
- Sweetness - 200x

Characteristics
- Not metabolized, non-caloric
- Aftertaste similar to saccharin
- More stable than aspartame to acid and heat
Acesulfame

- FDA approved acesulfame on 7/28/88, after only 6 years of regulatory review
L-Sugars

- These are “mirror images” of the commonly naturally occurring D-sugars
- They are not susceptible to normal carbohydrate metabolizing enzymes. Sweetness (L-fructose) = 1.8x
- Regulatory history
  - Petition filed for L-fructose
  - L-tagatose GRAS petition approved April 11, 2001
Trichlorogalactosucrose
Trichlorogalactosucrose

- Discovered by Hough and Khan - 1976
- Synthesized from table sugar
- Sweetness = 650x
- Regulatory history
  - Approved in Canada and other countries for several years
  - Approved in US April 1, 1998
- Trade name = Splenda
Trichlorogalactosucrose

- **Safety considerations**
  - Heat stability of a chlorinated organic? Apparently not a problem
  - Enzyme resistance - low calorie
  - $LD_{50} = 16 \text{ g/kg} \ (\text{very non-toxic})$
Taste Profile

Sucralose Tastes Like Sugar

Source: National Food Laboratories
Neutral Water, 9% Sucrose Equivalent
Monellin

- Discovered by Morris and Cagan - 1972
- A plant extract from the west African shrub, *Dioscoreophyllum cumensii* (the Serendipity berry)
- Composed of two non-identical sub-units, A and B. The individual sub-units are not sweet by themselves and dissociate at low pH.
Monellin

Sweet...

But on addition of acid, not sweet
Temporal problem with monellin
Monellin

- **Sweetness = 3000x**
- **Regulatory history - none**
- **Safety considerations - unknown**
Thaumatin

- Discovered by Inglett and May - 1968

- A plant extract from the west African shrub, *Thaumatococcus danielli*. The sweetness is derived from the mucilagenous gel in the berries and is destroyed by heat.
Thaumatin

- Sweetness = 1500-2000x
- Marketed in Europe as Talin
- Regulatory history (US) - none
- Safety considerations
  - Used for centuries by Africans of the region to sweeten bread and palm wine
Source of thaumatin

Source of thaumatin protein
Glycyrrhizin

- Extract from the roots of *Glycyrrhiza glabra* which grows in Europe and Central Asia

- Provides a licorice flavor in addition to sweetness. Also, it is a sweetness (flavor) potentiatior.
Glycyrrhiza glabra

The licorice plant
Glycyrrhizin

- Sweetness = 50-100x
- Commercial name - Magnasweet
- Regulatory history
  - GRAS substance
- Safety considerations
  - Unknown
Stevia

- A genus of herbs in the sunflower family
- Known as sweet leaf, sugar leaf or stevia
Stevia

- Extracts have relative sweetness up to 300 times that of sugar
- Leaves themselves are 30-45 times as sweet as sugar
- Coca Cola/Cargill product: Rebiana
- Cargill product: Truvia
- PepsiCo product: PureVia
Steviol

Steviol

Stevioside

Rebaudioside A
Uses

- Legal in US
- Received GRAS approval, Fall 2008
- Approved for food use in other countries as well
- Improves insulin sensitivity and may be useful in treatment of diabetes and metabolic syndrome
Safety

- Studies have been a mixed bag so far but there is little in any of them to indicate that Stevia is harmful.
- 2008-WHO: not genotoxic and not carcinogenic; may be helpful in patients with hypertension and type-2 diabetes.
Safety

- FDA granted GRAS approval to Coca-Cola/Cargill and Whole Earth/PepsiCo