BAKING SCIENCE & TECHNOLOGY
Science
Sweeteners; Fats and Oils
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REV DATE: 12/2016
Science: Sweeteners; Fats and Oils

Overview

We will start with understanding a little of the chemistry of sugars. Sucrose has historically been the primary sweetener used in baked goods, so we will look at various types of sucrose used, and then compare other common sweeteners to sucrose. Non-nutritive sweeteners will be briefly examined.

Traditional fats will be discussed, along with the methods used to produce them. Additionally, we will look over the rapidly-changing mix of fats and oils available to bakers.

Purpose

Sugars and fats are included in the majority of bakery products, at variable levels. It is important to understand the differences in options available to you, in order to either make the proper selection or to anticipate changes in processing/production with changes in ingredients.

Objectives

After completing this section of the course, you will be able to:

- Select functions of sweeteners (for a variety of bakery products)
- Define terms used to differentiate common sugar forms and browning reactions
- Calculate sugar replacement, based on total solids, fermentable solids, or sweetness
- Analyze characteristics of common sugars, such as forms of sucrose, molasses, honey, invert, and malt
- Explain dextrose equivalent, and its application to glucose syrups
- Appraise characteristics of various dextrose / high fructose products
- Rank crystallizing and browning rates of various sweeteners
- Describe alternative sweetener categories
- Identify general characteristics of fats and oils; saturated and unsaturated fatty acids
- Distinguish properties of common bakery oils and fats
- Analyze oil / fat processing steps
- Examine potential problems associated with fats / oils
- Explain typical fat / oil specifications
**Sweetener Functions**

Sweetening
Tenderizing
Stabilizing
Fermentation control
  - Yeast nutrient
  - Osmotic pressure
Bulking agent (body)
Flavor
  - Molasses, Honey, Malt
Browning
Humectant
Texture
Shelf-life

**Monosaccharides**

Greek words
  - “Mono” = one
  - “Sakcharon” = sugar
  - “ose” ending indicates sugar
Simple sugars
  \[(CH_2O)_n\]
Isomers = compounds with different structures but the same molecular formula
Pentose: \(n = 5\); \(C_5H_{10}O_5\)
  - 5 carbon sugars
  - Common pentose isomers
    - Arabinose, Xylose, Ribose
Hexose: \(n = 6\) ; \(C_6H_{12}O_6\)
  - 6 carbon sugars
Monosaccharides Continued

Common hexose isomers

Glucose (or dextrose)
   From starch
Fructose (or levulose)
   From high DE syrups (which come from starch)
Galactose
   In milk
Saccharides

Disaccharides = _____ sugar molecules joined together

Only disaccharides and monosaccharides are sugars on US food label

Trisaccharides = _____ sugar molecules joined together

Not “sugar” on US food label

Tetrasaccharides = _____ sugar molecules joined together

Not “sugar” on US food label

Disaccharides

Combination of 2 monosaccharides

\[ C_6H_{12}O_6 + C_6H_{12}O_6 = C_{12}H_{22}O_{11} + H_2O \]

Lactose = ____________________________________________________

From milk

Maltose = ____________________________________________________

From starch

Sucrose = ____________________________________________________

From sugar cane/beets

Reducing Sugars

Able to cause color change in specific solutions

Because sugar’s carbonyl is “free” or available for reaction

Carbonyl is the reactive part of the sugar

Refer to Figure 2 in Reading Materials, page 3

Glucose, fructose, and galactose

Xylose, arabinose, and ribose

Maltose and lactose

Therefore, non-reducing = sucrose

Only common non-reducing sugar
Browning

Maillard reaction

Rapid color produced by complex reaction between:

Reducing sugars and
Proteins (amino acids or amine compounds)
With heat
Yields a variety of brown-colored products
Basis for browning and aroma-flavor formations associated with heated foods
Crust color for many bakery products

Caramelization

Reaction of sugars and heat
“Burned sugar”
Does not involve amine groups

More Sugar-related Terms

Monohydrate

Has 1 molecule of water associated
Can easily be removed
\[ C_6H_{12}O_6 \cdot H_2O \]
Common form of dextrose

Anhydrous

Has 0 molecules of water associated
\[ C_6H_{12}O_6 \]

Fermentable Sugars

Yeast must have specific enzymes to hydrolyze (ferment) sugars
What are the common sugars utilized by yeast?
Calculating Fermentable Solids

$$C_{12}H_{22}O_{11} + H_2O \rightarrow C_6H_{12}O_6 + C_6H_{12}O_6$$

$$MW = 342.30 \rightarrow 360.31$$

MW is molecular weight

Disaccharides actually “gain weight” during fermentation!

$$\frac{100}{342.30} = \frac{X}{360.31} = \frac{\% \text{ solids}}{\text{MW}}$$

$$X = \left(\frac{100 \times 360.31}{342.30}\right) = 105.26\% \text{ solids}$$

<table>
<thead>
<tr>
<th>Sweetener</th>
<th>Total % Solids</th>
<th>Fermentable % Solids</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sucrose</td>
<td>100</td>
<td>105.26</td>
</tr>
<tr>
<td>Maltose</td>
<td>100</td>
<td>105.26</td>
</tr>
<tr>
<td>Fructose</td>
<td>100</td>
<td>100.00</td>
</tr>
<tr>
<td>Dextrose</td>
<td>91.5</td>
<td>100.00</td>
</tr>
</tbody>
</table>

% fermentable solids is based on total solids

Approximate Sweetness Levels

Refer to Table 13, page 46 (and page 8, Reading Materials)

Calculation Practice

Refer to Additional Practice at end of homework
Sugar (Sucrose) Processing
Sucrose is considered the standard sweetener for foods

- Commonly “sugar” = sucrose

Sugarcane processed in New Guinea > 8,000 years ago
Sugar beet processed > 400 years ago

Raw cane sugar
- Cane is washed and chopped, shredded, or crushed
- Passed through rollermills with hot water to remove sugar

Raw beet sugar
- Beets are washed and sliced
- Hot water used to remove sugar

Many additional refining steps required to produce pure sucrose

- Series of washing, centrifugation, evaporation, and filtering

Obtain essentially ________________ sucrose

“Dried cane syrup”
- Obtained after first sucrose crystallization
- US FDA’s acceptable term

- “Evaporated cane juice” no longer acceptable on US labels

Turbinado, sucanat, muscovada, demerara, black sugar, mauritius, jaggery, and ...

- Various forms of partially refined sugar
- Vary in color and particle size
- Sometimes sold as “raw sugar”

Granulated sugar (sucrose)

- No significant difference in baking between cane or beet source
- Solubility in water 2:1

- “Simple syrup”
- Saturation is 67%

Baking application determines the sugar type needed

- Generally defined by particle size

- What is “bakers special”?
Sugar (Sucrose) Processing Continued

Powdered sugar

Use: avoid grittiness; visual effect

Specially ground granulated

2X - 12X

More X’s indicates ______________________________________________________________________

Probably contains dried (corn) starch or tricalcium phosphate

Liquid sucrose

Easily handled in bulk

Some companies are replacing corn syrups / glucose syrups with liquid sucrose

Microorganism growth potential problem

Fondant

Generally retail sweet-goods use

Plastic mass of microscopic sugar crystals in a matrix of a saturated sugar solution

Paste or dry

Rolled fondant used on fancy cakes

Molasses (Treacle)

By-product of sucrose refining

Used for flavor, color, and moisture retention

Acidic

Grades depend on purity

Vary in flavor, color, and fermentable sugars

“Highest grade” has most total sugars and least ash
Sulfured versus unsulfured
Sulfur is bleaching process
Dry molasses
Blend of molasses and carrier (starch, flour, dextrins, etcetera)

**Brown Sugar**
Traditionally crystallized dark syrups
Commonly blend of 85-90% sucrose and 15-10% molasses
Grades vary by color (and flavor)
Different molasses and different percentages

**Invert Sugar (Syrup)**
Sucrose treated with acid and/or enzyme
______________________________ to hydrolyze
Creates equal mixture of glucose and fructose
And some sucrose
Hygroscopic (used as humectant)
Vary in % sucrose and % invert

<table>
<thead>
<tr>
<th>(solids basis)</th>
<th>Medium</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dextrose</td>
<td>27-30%</td>
<td>48-50%</td>
</tr>
<tr>
<td>Fructose</td>
<td>27-30%</td>
<td>48-50%</td>
</tr>
<tr>
<td>Sucrose</td>
<td>46-40%</td>
<td>4-0%</td>
</tr>
</tbody>
</table>
Honey
Slightly different flavor, aroma, and color
- Varies with flower source of bees
- Examples: orange, clover, sage, and buckwheat
May contain functional antioxidants
“Natural invert sugar”?
- “Natural” = yes
- “Invert sugar” = no
  Fructose to glucose ratio varies
  Ratio is important for preventing

Used in breads as well as desserts / sweet products
Most commercial honey is heat processed
- Remove sugar crystals
- Inactivate amylase and ...
Dry honey
- On carrier

Malt (Syrups)
Produce malt (carefully germinated barley and/or other cereal)
- Coarsely grind malt, ferment to hydrolyze starch
  - Use grain’s own enzymes
- Evaporate, perhaps spray dry
- Vary in color
Rich source of maltose
- And dextrins, minerals, soluble proteins, and enzymes
Diastatic = enzyme active
Nondiastatic = enzyme inactive
Sweetener
Raisin Juice Concentrate

Extract from raisins
- 70% sugars
Color is amber to dark brown
Helps control mold
- Contains 2% tartaric acid

Maple Syrup

From sap of maple trees
- 60% sugars
Unique flavor
Dark color
Very expensive

Dextrose Equivalents

Corn syrups (also called glucose syrups), in some form, are common sweeteners
Selected or described by DE
- Dextrose equivalents
- Very confusing term
Measure of the reducing sugar content
- Measure of the free carbonyls (reactive groups)
- Indicates broken amylose and/or amylopectin chains
- Expressed as percentage of total potential reducing groups in the solids
- “Destruction Equivalent” is my preferred term
Remember that glucose is a reducing sugar
Maltose: 1 glucose molecule is reducing and 1 is not
- 50% “free” reacting groups or carbonyls
- 1/2 x 100 =50 DE
Dextrose Equivalents Continued

Starch: only 1 reducing group per starch molecule

\[
DE = \frac{1}{1,000,000} \times 100 = 0
\]

All other glucose molecules linked at the C-1 position

With each break by amylases or acid, one reducing group of glucose molecule is freed

DE is measure of reducing groups compared to a dextrose standard of 100

- If have dextrin chain of 10 glucose linked, \( DE = \frac{1}{10} \times 100 = 10 \)
- If break 1 linkage, \( DE = \frac{2}{10} \times 100 = 20 \)
- If break 3 linkage, \( DE = \frac{4}{10} \times 100 = 40 \)
- If break all linkages, \( DE = \frac{10}{10} \times 100 = 100 \)

DE tells the per cent bonds broken

“Destruction equivalent” again

Not the chemical composition of the syrup

62 DE syrup is not 62% dextrose
Dextrose Equivalents Continued

What would you expect to be the functional differences?

DP = degree of polymerization or how many glucoses are together

<table>
<thead>
<tr>
<th>Syrup A</th>
<th>Syrup B</th>
</tr>
</thead>
<tbody>
<tr>
<td>15% dextrose (DP1)</td>
<td>34% dextrose (DP1)</td>
</tr>
<tr>
<td>20% maltose (DP2)</td>
<td>30% DP10</td>
</tr>
<tr>
<td>28% DP4</td>
<td>36% DP18</td>
</tr>
<tr>
<td>25% DP5</td>
<td>DE = 39</td>
</tr>
<tr>
<td>12% DP6</td>
<td>DE = 39</td>
</tr>
</tbody>
</table>

The higher the DE, the greater the extent of starch hydrolysis (break down)

Resulting in a smaller average polymer size

Primarily indicates fermentability and sweetness of syrups
Corn (Glucose) Syrups

Most of the world uses term “glucose syrups” or “starch sugars”

Corn wet-milling produces corn starch
   Which is then further processed to wide variety of syrups

Starch must be gelatinized:
   In presence of acid or by jet cooking
      Reduces viscosity
      Called “liquefaction” or “thinning”

Add enzymes
   Which vary, depending upon desired syrup type

Maltodextrins
   DE less than 20
      Commonly 1, 5, 10, 15, or 18 DE
   Made with acid or combination of acid and α-amylase
   Useful as viscosity builders

High-maltose syrups
   Specifically create maltose from starch
   Use pullulanase and β-amylase
      Pullulanase = “debranching” enzyme
      “Pulls off” the branches of amylopectin

Mid-DE syrups
   24 to 82 DE are available
   42 and 62 / 64 DE most common for baking
      Remember – three different 42 DE syrups could have three
different sugar compositions

Starch hydrolysate
   Consists mostly of dextrose
   DE at least 80
Corn (Glucose) Syrups Continued

High DE syrups

92-95 DE common

Made using amyloglucosidase

- Enzyme that produces glucose from nonreducing ends of starch
- Breaks $\alpha$-1,4 and $\alpha$-1,6 bonds

High-fructose (corn) syrup

- Also called glucose fructose syrup
- Start with 95 DE syrup
- Glucose isomerase converts glucose to fructose
  - Same formula, different 3-dimensional structure
- 42% HFCS
  - 42% fructose, approximately 53% glucose and 5% higher "sugars"
  - Similar sweetness to sucrose
    - When compared on equal solids basis
- 55% and 90% fructose require further processing (fractionation)
  - To remove fructose, allowing reaction to continue
**Corn (Glucose) Syrups Continued**

**Syrup Storage**

- High enough temperature to keep from crystallizing
  - Glucose / dextrose is the problem
- Low enough temperature to keep from caramelizing

**Examples of Syrup Storage Temperatures**

<table>
<thead>
<tr>
<th>Product</th>
<th>°F</th>
<th>°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>42 and 62 DE</td>
<td>90-100</td>
<td>32-38</td>
</tr>
<tr>
<td>95 DE</td>
<td>130</td>
<td>54</td>
</tr>
<tr>
<td>42 &amp; 55 % HFCS</td>
<td>80-85</td>
<td>27-29</td>
</tr>
<tr>
<td>90% HFCS</td>
<td>70-80</td>
<td>21-27</td>
</tr>
<tr>
<td>Medium Invert</td>
<td>90</td>
<td>32</td>
</tr>
</tbody>
</table>

Why are these different?

**Syrup solids**

- Dried products of any syrup
  - Commonly 20, 24, and 44 DE
- Hygroscopic

**Dextrose (or glucose)**

- Crystallized from 95 DE syrup
- Generally monohydrate
- Regular, powdered, or pulverized
Corn (Glucose) Syrups Continued

Dextrose (or glucose) continued

Not readily soluble in water

Solubility is 1:1

Saturation is 50%

Forms large crystals

Less sweet than sucrose

Browns at lower temperature than sucrose

Depresses freezing point (if soluble)

Fructose

Crystallized from HFCS

Regular, powdered, or pulverized

Solubility in water is 4:1

Saturation is 80%

Sweeter than sucrose

Browns at lower temperature than sucrose

Depresses freezing point (if soluble)

Effect of Temperature on Sweetener Solubility

Effect of Temperature on Sweetener Solubility

Change 68° to 104°F (20° to 40°C)

Invert changes 16%

Dextrose changes 14%

Sucrose changes 4%
Other “Common” Sweeteners

Syrups from non-corn starches
  Brown rice, wheat, oats, tapioca, sweet potato, ...
  Sometimes called hydrolyzed ____________ flour or ____________ extract

Fruit juice concentrates
  Apple, pear, dried plum, grape

Comparative Browning Rates

Fructose > glucose > lactose > maltose > sucrose

Comparative Crystallization

Difficult to crystallize
  Fructose
Readily crystallized
  Sucrose
  Dextrose – most readily crystallized

Alternative Sweeteners

Sweeteners discussed so far are “nutritive”
  Have 4 Cal/g
  Contribute a significant portion of a food’s energy value
  Have multiple functions
Alternative = different, non-traditional, less functional
Often use combinations of alternative sweeteners
May act synergistically
  With traditional sweeteners and/or alternative sweeteners
No legal definition of “natural”
Alternative Sweeteners Continued

Agave syrup
- Varies in color (and composition)
- High in fructose (56-92%)
- Sweetness = 140-160
- “Natural” sweetener
- Also called “hydrolyzed inulin syrup”

Palm sugar or syrup (coconut sugar or syrup)
- Extracted from flower bud sap
- Sweetness similar to sucrose
- “Natural” sweetener

High intensity sweeteners
- Sweetness more than 30 times that of sucrose (approximately)
  - RS is relative sweetness to sucrose
  - 300 RS = 30,000 sweetness level
- Often diluted or extended with carrier
- Effectively noncaloric
  - Because we use such a small amount
  - Acesulfame K (ex: Sunette; Sweet One; Swiss Sweet)
  - Advantame
  - Aspartame (ex: NutraSweet; Equal)
  - Neotame
  - Saccharin (ex: Sweet ‘n Low; Sweet Twin; Necta Sweet)
  - Sucralose (ex: Splenda)

US approved “natural” high intensity sweeteners
- Stevia extracts (ex: Truvia, PureVia, Good&Sweet Reb-A)
  - From South American plant
  - Extracts (Rebiana or Reb-A, Reb C, Reb M, Reb D) generally approved for food
  - Sweetness = 300 RS
  - Heat and pH stable
Alternative Sweeteners Continued

US approved “natural” high intensity sweeteners continued

Monk fruit (Luo Han Guo, rakanka, lohan kuo)
From southern Chinese plant
Heat stable
Sweetness = 300 RS in pure form
Mogroside V is active component

Bulk sweeteners
Used for weight and volume
Provide calories
Usually less than sucrose
Sweetness levels more comparable to traditional sweeteners

US approved “natural” bulk sweeteners

Tagatose
Sweetness = 92; 1.5 Cal/g
Mirror image of fructose
Reducing sugar

Trehalose
Sweetness = 45; 4.0 Cal/g
2 glucoses linked α-1,1
May help reduce freeze-thaw damage to yeast

Isomaltulose (Palatinose)
Sweetness = 50; 4.0 Cal/g
Enzymatic conversion of sucrose
Reducing sugar

Allulose or psicose (Dolcia Prima)
Sweetness = 70; 0.4 Cal/g (?)
Reducing sugar
Enzymatic conversion of fructose
Alternative Sweeteners Continued

US approved “natural” bulk sweeteners continued

Polyols

Debate on “natural”

Also called sugar alcohols or polyalcohols

Reducing group has been converted to nonreducing group

Isomalt (Palatinit)

Lactitol

Maltitol

Sorbitol

Mannitol

Xylitol

Erythritol

See enlarged table of “Polyol Properties” page 47

General Functions of Baking Fats and Oils

Shortens texture (tenderizing)

Lubrication

Machinability

Aeration (creaming)

Flavor

Shelf-life extension

Heat transfer

Nutrition

What are Fats and Oils?

One kind of lipid

Fats = solid or semi-solid at room temperature

Heated sufficiently they will melt

Oils = liquid at room temperature

Cooled sufficiently they will solidify
Science: Sweeteners; Fats and Oils

What are Fats and Oils? Continued

All fats and oils are triglycerides
  Glycerol backbone + 3 fatty acids = triglyceride
  Glycerol and glyceride are the same

Plastic fats or shortenings contain variable proportions of liquid (oil) and solid (fat)
  Soft solids

Fluid / pumpable shortenings also contain variable proportions of liquid (oil) and solid (fat)
  Cloudy liquids

Fatty Acids – Who Cares?

Fatty acid composition of fats and oils controls:
  Functionality
  Nutritional profile

Less-healthy fats often provide most desirable functionality

What are Fatty Acids?

Chains of carbon atoms
  Various lengths (usually even number)
  Many hydrogens and 2 oxygens attached to carbons
  May or may not have double bonds between carbons

Fatty Acid Examples

\[ \text{Butyric or C4} \]

\[ \begin{align*}
\text{Fatty Acid Examples} & \\
\text{Continued} & \\
\text{C}_3\text{H}_7\text{COOH} & \\
\text{H} & \text{H} & \text{H} & \text{O} \\
\text{H} & \text{C} & \text{C} & \text{C} & \text{C} & \text{C} & \text{C} - \text{OH} \\
\text{H} & \text{H} & \text{H} & & & & \\
\text{Butyric or C4} & \\
\text{C}_5\text{H}_{11}\text{COOH} & \\
\text{H} & \text{H} & \text{H} & \text{H} & \text{H} & \text{H} & \text{O} \\
\text{H} & \text{C} & \text{C} & \text{C} & \text{C} - \text{C} & \text{C} - \text{C} - \text{C} - \text{OH} \\
\text{H} & \text{H} & \text{H} & \text{H} & \text{H} & \text{H} & \\
\text{Caproic or C6} &
\end{align*} \]
Major Fatty Acids

Major Fatty Acids (Saturated)

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<thead>
<tr>
<th>Fatty Acid</th>
<th>Size</th>
<th>Melting Point</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>°F</td>
</tr>
<tr>
<td>Butyric</td>
<td>C4</td>
<td>17</td>
</tr>
<tr>
<td>Caproic</td>
<td>C6</td>
<td>24</td>
</tr>
<tr>
<td>Caprylic</td>
<td>C8</td>
<td>62</td>
</tr>
<tr>
<td>Capric</td>
<td>C10</td>
<td>87</td>
</tr>
<tr>
<td>Lauric</td>
<td>C12</td>
<td>111</td>
</tr>
<tr>
<td>Myristic</td>
<td>C14</td>
<td>130</td>
</tr>
<tr>
<td>Palmitic</td>
<td>C16</td>
<td>145</td>
</tr>
<tr>
<td>Stearic</td>
<td>C18</td>
<td>157</td>
</tr>
</tbody>
</table>

Saturated

No double bonds in carbon chain
Full of hydrogens

Monounsaturated (MUFA)

One double bond in carbon chain

Polyunsaturated (PUFA)

Two or more double bonds in carbon chain

Major Fatty Acids Continued

Saturated Fatty Acids

- Fatty acid contains only single bonds between carbons, resulting in a straight chain
- Usually solid (or crystalline) at room temperature
- Long shelf-life (stable; not rancid)
Major Fatty Acids Continued

Unsaturated Fatty Acids
(Cis; Talk About Trans Later)

- Fatty acid contains one or more double bonds, where angle or bend in chain occurs
  - Liquid (or non-crystalline) at room temperature
    - Bent molecules cannot pack together as closely as straight molecules
  - More susceptible to rancidity
    - Less stable; shorter shelf-life

Unsaturated Fatty Acids
Continued

<table>
<thead>
<tr>
<th>Fatty Acid</th>
<th>Carbons</th>
<th>Melting Point</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Dbl bonds</td>
<td>°F</td>
</tr>
<tr>
<td>Stearic</td>
<td>C18:0</td>
<td>157</td>
</tr>
<tr>
<td>(saturated)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| Oleic      | C18:1    | 61  | 16.1 |
| Linoleic   | C18:2    | 21  | -6.1 |
| Linolenic  | C18:3    | 9   | -12.8 |
| (all 3 are unsaturated)| |  |  |

Solid Fat Crystal

Liquid Fat (Oil)

All fatty acids are not actually identical
Properties of Fats

Triglycerides

All fats or oils
Mixture of fatty acids
  “Random
  What those fatty acids are determines the functionality of the fat or oil

Variations in amount of unsaturation

Melting point
  More unsaturated has lower melting point
  More saturated has higher melting point
  Type of fatty acid in 2 (or β) position of glycerol is most important

Oxidative rancidity
  More saturated is more stable
    Stable = more protected against rancidity

Nutrition
  Saturated generally considered less healthy
    May vary with chain length

Variations in chain length
  Shorter chain has lower melting point
  Longer chain has higher melting point
Properties of Fats Continued

Melting point impacts texture as well as functionality

- Too low melt point can appear / feel oily in finished product
- Too high melt point can appear/ feel waxy in finished product

Plastic (soft solid) range

- Temperatures between which shortening has a suitable consistency for use
  - In creaming
  - Or otherwise being worked

Available Fat/Oil Products

Fats and oils are the most rapidly changing category of ingredients

- Decrease use of animal fats
- Decrease / eliminate hydrogenation
- New seed sources / processing methods
- New (?) emphasis on nutrition
  - Decrease calories in diet
  - Increase specific types of fats / oils

Lard

- Fat from pigs (hogs, swine)
- No natural antioxidants
- Variable consistency
- “Specialty use”
  - “Superior shortening” properties
  - High melting point

Tallow

- From any animal other than pig
  - Usually beef or sheep fat
- No natural antioxidants
- Used as hard fat in blended shortenings
  - A/V shortenings
Available Fat/Oil Products Continued

Butter

- Milk fat
  - Potential allergen (milk protein)
- No natural antioxidants
- Distinctive flavor
- Low melting point
- Narrow plastic range
  - Butter has limited creaming properties
- Water-in-oil emulsion
  - At least 80% butterfat (USA)
  - Remaining weight (< 20%) is water and/or salt

Margarine

- Similar to butter
- Water-in-oil emulsion
  - At least 80% fat (USA)
    - Soy, cottonseed, etcetera
    - Remaining weight (< 20%) is water and/or salt and/or other ingredients
- Table grade mimics butter
- Baker’s margarines – “fit your needs”
  - Higher melting point
  - More waxy consistency
  - Wider plastic range

Cocoa butter (chocolate)

- Only seed fat that is true solid at room temperature
- Unique combination of fatty acids
- Very narrow melting range
  - Below body temperature
  - Brittle below 80°F (27°C)
  - Melts 93-95°F (34-35°C)
Available Fat/Oil Products Continued

“Tropical” oils

High in mid-chain length saturated fatty acids

Coconut oil

Over 90% saturated fatty acids

Semi-solid at room temperature

Only “highly refined” has no allergen potential

Palm kernel oil (PKO)

Oil extracted from nut or seed

Palm oil

From fruit pulp

Lower saturated, higher monounsaturated fatty acids than other “tropical oils”

Primarily C16:0 and C18:1

Currently an important oil source

Mostly monounsaturated oils (predominately C18:1)

Canola

Highest % unsaturated

US FDA qualified health claim

Olive

Peanut

Only “highly refined” has no allergen potential

Mostly polyunsaturated oils (predominately C18:2)

Corn

Cottonseed

Safflower

Soy

Only “highly refined” has no allergen potential

Sunflower
Available Fat/Oil Products Continued

Trait-enhanced (stable) oils

Genetic variations to decrease polyunsaturated and increase monounsaturated fatty acids

- Mostly non-GMO (not genetically modified, genetically engineered, biotech)

Novel sources of oils

- Oats
- Amaranth
- Rice bran
- Fish
- Algae
- Flax / chia / hemp
- Tigernut
- Avocado
- Ecetera

Trans Fatty Acids

Form of unsaturated fatty acids

- Physical or geometric isomer (different shape)

Many, many countries either require labeling or have maximums

Latin prefixes

- Refers to location of hydrogens attached to carbons involved in double bond
- Cis = on same side
- Trans = on opposite side
Trans Fatty Acids Continued

“Trans” fatty acids produce very different biological functions than “cis” fatty acids

- Raise the “bad” (LDL) cholesterol
- Lower the “good” (HDL) cholesterol
- Increases risk of ____________________________

Changes functionality

- More stable to rancidity than cis form
- Higher melting point than cis form
- Lower melting point than saturated chain of same length

Primarily created as side-reaction of hydrogenation (and deodorization)

Trans-Free or Low-Trans Fats

Many solutions are available, all have “trade-offs”

- Cost, functionality, increased saturated fats

Bakeries may need more types of shortenings (more product specific) than before

Tend to be:

- Less stable (greater chance of rancidity)
- More sensitive to temperatures changes
- Different textures and colors
You Need to Understand....

Most sources are ________________

Liquid

Many applications (especially sweet goods) require at least some

__________________

Some solids

What “magic” can be used to change oil to shortening?

Liquid to semi-solid

Option 1 (Oils to Shortening)

Hydrogenation

Oldest optional process for highly refined oil conversion to shortening

Used to create PHO or partially hydrogenated oils

Hydrogen is added to the double bond carbons

Easily controlled

PUFA to mono preferred (18:3 or 18:2 to 18:1)

Raises melting point

Retards oxidative rancidity

Increases stability

Full hydrogenation leads to a saturated fat

Partial hydrogenation can lead to trans fatty acids

US FDA rescinded the generally recognized as safe (GRAS) status of partially hydrogenated oils (PHO) effective June 18, 2018

Many countries keeping limit on trans fatty acid content

Many changes happening in shortenings
Option 2 (Oils to Shortening)

Interesterification

Newer optional process for highly refined oil conversion to shortening

Modifies where the fatty acid chains are attached to the glycerol molecule

Detaches fatty acids, followed by random reattachment

2 or β position is most important in determining melting point / texture

Usually fractionate (based on melting point), pick what want, and recycle the rest

Separates the “softer” oil portion from the “harder” oil/fat portion

Fractions can be blended with other oils

Interesterification (Simplified)

Raises melting point
May retard rancidity
Depending on which fatty acids are included in the mixture

Option 3 Through ??

Many other options available to produce shortening

Fractionation

Oil blends

Trait-enhanced oilseeds

Emulsifiers

Animal fats
Option 3 Through ?? Continued

Recent novel options (examples)

Use interesterification combined with fiber or starch
  Fiber reduces the problem of wicking (migration of liquid
  oil out of crystalline structure)

Oleogels or organogels
  Use polyols as gelling agents to solidify oils

Remember....

Some bakery product use oil

Some bakery product use ________________ shortening
  Stable mixture of oil in fat (liquid trapped in solid)
  Behaves more like fat

Some bakery product use ________________ shortening
  Stable mixture of fat in oil (solid trapped in liquid)
  Behaves more like oil

Processing of Oils

Oil is removed from source seed

  Heat, pressure, solvents

  Solvent is then removed and recycled

  “Expeller-pressed” or “cold-pressed” use no solvents

  Only pressure and lower temperature than solvent
  extracted oil

  Contain more non-oil contaminants, including potential
  allergens

Purification (produce “highly refined” oil; also called RBD – Refined
Bleached Deodorized)

  Start with solvent extracted oil

  Remove phospholipids, free fatty acids, proteins (important for
  allergens)

  Bleached

  Deodorized (remove odors)
Processing of Fats

If need to create more solids (make fats) use optional treatments (previously discussed)

Hydrogenation
Interesterification / fractionation
Blending

Votation (heat exchanger)
Simultaneous chilling and mixing
Solidifies shortening under controlled conditions
Purpose: promote the formation of specific crystal sizes
May be done at bakery

Tempering (of most shortenings and margarines)
Hold under specific temperature to help the desired crystal “set”
Maintains desired crystal size
Ensures that the solid fat crystals stay the right size
Proper storage temperatures are also important

Powdered shortening or powdered oils
Mixture of maltodextrin and fat/oil
Agglomerated

Spray crystallization
Atomized liquid fats and/or oils come into contact with liquid nitrogen
Solidify instantly into free flowing particles

Crystalline Structure

So, why worry about fat crystals?

Fats are polymorphic
Exist in many forms of crystals
Impacts functionality
Crystalline Structure Continued

Type of crystals present depends on:

- Source of fat / oil and processing conditions
- Method of votation
- Time and temperature of tempering
- Presence of additives (emulsifiers, crystal modifiers)
- Storage conditions (time and temperature)

  This is where bakers can “mess up” good shortening

Beta prime- (β′-) crystal

- Small delicate crystals

  Shortening has
  
  - Smooth appearance
  - Lower melting point
  - Extended plastic range
    
    Needed for creaming

  Ability to produce high-volume, fine-textured cakes

Beta- (β-) crystal

- About 20 times larger than beta prime crystals

  Shortenings have grainy texture

  Lack aerating power needed for cakes

  Good shortening properties

Problems with Fats and Oils

Oxidation (Autoxidation)

Oxygen reacts with double bond of unsaturated fatty acids

  Reaction with air at room temperature in “chain reaction”

Develop objectionable flavors and odors (rancidity)

  Rancid = stinky, bad-smelling and bad-tasting

  Definitely NOT what you want to use in production
Oxidation (Autoxidation) Continued

Fat/oil characteristics that accelerate oxidative rancidity

- Degree of unsaturation in fatty acid chains
- How many double bonds in one chain
- Proportion of unsaturated fatty acids in fat/oil
- How many total double bonds

Stability – Relative Oxidation Rates

<table>
<thead>
<tr>
<th>Fatty Acid</th>
<th>Oxidation Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>C18:0 (Stearic Acid)</td>
<td>0 or 1</td>
</tr>
<tr>
<td>C18:1 (Oleic Acid)</td>
<td>10</td>
</tr>
<tr>
<td>C18:2 (Linoleic Acid)</td>
<td>100-120</td>
</tr>
<tr>
<td>C18:3 (Linolenic Acid)</td>
<td>125-250</td>
</tr>
</tbody>
</table>

Storage conditions that accelerate oxidative rancidity

- Heat
- Moisture
- Air
- UV light
- Some metals (copper, iron and brass)

Lipoxygenase

Enzymatic rancidity

- Polyunsaturated fats only
- Present in wheat germ and enzyme active soy / pea flour
- Also bleaches flour and increases mixing tolerance
Lipase

Enzyme that causes hydrolysis
  Breaks apart fats and oils
  Breaks off or removes fatty acids from glycerol backbone

Free fatty acids are more reactive
  Therefore, are more susceptible to oxidation or saponification
    (soap making)

Polymerization

Chemical reaction resulting in unsaturated fatty acids joining together
  Opposite of hydrolysis

Particular in fryers or ____________________________
  Forms “gums” or “varnish” on edges
  May cause foaming in fryer
Fats and Oils Specifications

Antioxidants – An Optional Addition

If present, slow the development of oxidative rancidity

- By interrupting the oxidative chain reaction
- Cannot reverse the oxidation of rancid oils

Bakers prefer heat-stable forms
- Protect oil or shortening prior to use
- Protect in the finished product

Traditional (“chemical”) antioxidants
- TBHQ (tertiary butyl hydroquinone)
- BHA (butylated hydroxyanisole)
- BHT (butylated hydroxytoluene)
- Propyl gallate
- Citric Acid
  - For metal-induced reactions

Lecithin
- Limited antioxidant properties

Extracts (most available forms are heat stable)
- Rosemary
- Sage
- Green tea
- Sesame oil
- Olive juice
- Brown or black rice bran
- Licorice
- Etcetera
Science: Sweeteners; Fats and Oils

Peroxide Value (PV)
Indicates extent that oil / fat has already reacted with oxygen
- Measures rancidity that has already started
- Check that oil has been properly refined and handled (no abuse has occurred)
- The higher the PV, the higher the possibility of off-flavors
Important for ??

Iodine Value
Measures degree of unsaturation (number of double bonds)
Higher Iodine Value means more double bonds
- Hydrogenation lowers IV
- So, stability increases as IV decreases (generally)
Important for ??

Oil Stability Index (OSI)
Accelerated rancidity test
- Air bubbled through hot oil
- Break-down product continually measured
Used to predict stability
- High OSI should be resistant to rancidity for a long time
Important for ??

Free Fatty Acid (FFA)
Amount of unattached fatty acid present
Measured by simple titration with NaOH
High level indicates inadequate refining or breakdown
Free Fatty Acid (FFA) Continued

Typical specifications

Unused frying fat \(< 0.05\%\)

Specifications often \(< 0.1\%\)

Optimum (bakery) frying fat 0.3-0.75\%

Out-of-condition (bakery) fat \(> 1.0\%\)

Specifications will vary with product

Solid Fat Content / Solid Fat Index

Proportion of solid to liquid at given temperature

Not an indication of melting point of solid fats

High values imply that fat is hard at that temperature

One important characteristic of plastic shortenings

Slope of the curve very important for plastic fats

### Solid Fat Content Examples

<table>
<thead>
<tr>
<th>Temperature</th>
<th>All Purpose Shortening</th>
<th>Bakers Margarine</th>
<th>Butter</th>
<th>Lard</th>
<th>Pie Shortening</th>
<th>Puff Pastry Margarine</th>
</tr>
</thead>
<tbody>
<tr>
<td>50\°/10\°C</td>
<td>35</td>
<td>48</td>
<td>32</td>
<td>40</td>
<td>40</td>
<td>54</td>
</tr>
<tr>
<td>70\°/21\°C</td>
<td>26</td>
<td>25</td>
<td>12</td>
<td>27</td>
<td>17</td>
<td>36</td>
</tr>
<tr>
<td>80\°/27\°C</td>
<td>19</td>
<td>17</td>
<td>9</td>
<td>18</td>
<td>10</td>
<td>28</td>
</tr>
<tr>
<td>92\°/33\°C</td>
<td>12</td>
<td>11</td>
<td>3</td>
<td>11</td>
<td>6</td>
<td>20</td>
</tr>
<tr>
<td>104\°/40\°C</td>
<td>7</td>
<td>6</td>
<td>0</td>
<td>7</td>
<td>2</td>
<td>14</td>
</tr>
</tbody>
</table>

Melt Point

Temperature at which a solid becomes a liquid

Fat becomes oil

Varies with chemical composition (fatty acid) and crystal structure

Important for ??
Smoke Point

Temperature at which fat gives first trace of smoke when heated at specified rate

High smoke point desired for frying fat

420-450°F (215-232°C)

Also important for ??

Flash Point

Temperature at which heated oil gives flashes of burning when exposed to a flame

Frying fat: 326.7°C (620°F)

Fire Point

Temperature at which fat, heated under specified conditions, can be ignited by a test flame and burn for at least 5 seconds

Frying fat: 354.4°C (670°F)

Remember....

Plastic fats or shortenings contain variable proportions of liquid (oil) and solid (fat)

Soft solids

Fluid / pumpable shortenings contain variable proportions of liquid (oil) and solid (fat)

Cloudy liquid
Shortening Types

Bread oil

High-emulsifier cake shortening

High-stability shortening

Trough oil and divider oil

Pan oil
### Table 4
**Typical Molasses Composition**

<table>
<thead>
<tr>
<th></th>
<th>Imported</th>
<th>First</th>
<th>Third</th>
<th>Final</th>
</tr>
</thead>
<tbody>
<tr>
<td>% Solids</td>
<td>79.5</td>
<td>79.5</td>
<td>79.5</td>
<td>79.5</td>
</tr>
<tr>
<td>% Sucrose</td>
<td>35</td>
<td>34</td>
<td>36</td>
<td>34</td>
</tr>
<tr>
<td>% Invert</td>
<td>39</td>
<td>37</td>
<td>26</td>
<td>19</td>
</tr>
<tr>
<td>% Total Sugars</td>
<td>74</td>
<td>71</td>
<td>62</td>
<td>53</td>
</tr>
<tr>
<td>% Ash</td>
<td>2.0</td>
<td>2.3</td>
<td>5.6</td>
<td>9.5</td>
</tr>
<tr>
<td>pH</td>
<td>4.8</td>
<td>5.0</td>
<td>5.0</td>
<td>5.0</td>
</tr>
<tr>
<td>Color</td>
<td>0.2</td>
<td>0.3</td>
<td>0.8</td>
<td>1.5</td>
</tr>
</tbody>
</table>


### Table 7
**Typical Honey Composition**

| % Moisture | 18.3 |
| % Fructose | 41   |
| % Glucose  | 34   |
| % Sucrose  | 2.42 |

* Fructose:Glucose ratio varies

### Table 9
**Typical Corn or Glucose Syrup Composition**

<table>
<thead>
<tr>
<th></th>
<th>36 DE</th>
<th>42 DE</th>
<th>62 DE</th>
<th>95 DE</th>
</tr>
</thead>
<tbody>
<tr>
<td>% Solids</td>
<td>80</td>
<td>80.3</td>
<td>83</td>
<td>71</td>
</tr>
<tr>
<td>pH</td>
<td>4.7</td>
<td>4.7</td>
<td>4.7</td>
<td>4.5</td>
</tr>
</tbody>
</table>

**Dry Basis Composition**

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>% Glucose</td>
<td>15</td>
</tr>
<tr>
<td>% Maltose</td>
<td>12</td>
</tr>
<tr>
<td>% Trisaccharides</td>
<td>11</td>
</tr>
<tr>
<td>% Higher saccharides</td>
<td>62</td>
</tr>
</tbody>
</table>
## Table 10
### Typical High Fructose (Corn) Syrup Specifications

<table>
<thead>
<tr>
<th>% Solids</th>
<th>42%</th>
<th>55%</th>
<th>90%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry Basis Composition</td>
<td>% Solids</td>
<td>71</td>
<td>77</td>
</tr>
<tr>
<td>% Glucose</td>
<td>52</td>
<td>41</td>
<td>7</td>
</tr>
<tr>
<td>% Fructose</td>
<td>42</td>
<td>55</td>
<td>90</td>
</tr>
<tr>
<td>% Higher Saccharides</td>
<td>6</td>
<td>4</td>
<td>3</td>
</tr>
</tbody>
</table>

## Table 13
### Sweetness Ratings

<table>
<thead>
<tr>
<th>Sweetener</th>
<th>Rating&lt;sup&gt;(1)(2)&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sucrose</td>
<td>100</td>
</tr>
<tr>
<td>Dextrose (glucose)</td>
<td>80</td>
</tr>
<tr>
<td>Fructose</td>
<td>140</td>
</tr>
<tr>
<td>Maltose</td>
<td>40</td>
</tr>
<tr>
<td>Lactose</td>
<td>20</td>
</tr>
<tr>
<td>Galactose</td>
<td>32</td>
</tr>
<tr>
<td>Invert sugar (medium)</td>
<td>120</td>
</tr>
<tr>
<td>Invert sugar (total)</td>
<td>130</td>
</tr>
<tr>
<td>Molasses</td>
<td>70-90</td>
</tr>
<tr>
<td>42 DE corn syrup</td>
<td>40</td>
</tr>
<tr>
<td>62 DE corn syrup</td>
<td>70</td>
</tr>
<tr>
<td>95 DE corn syrup</td>
<td>80</td>
</tr>
<tr>
<td>42% HFCS</td>
<td>100</td>
</tr>
<tr>
<td>55% HFCS</td>
<td>110</td>
</tr>
<tr>
<td>90% HFCS</td>
<td>140</td>
</tr>
</tbody>
</table>

<sup>(1)</sup> Based on sucrose as 100  
<sup>(2)</sup> Syrup sweetness on a dry solids basis