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Did you miss Dr. Hartel’s “Ask Me Anything” on Reddit yesterday?

http://redd.it/2vizlq

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“Sweet Science: Chocolate Chemistry for Valentine's Day”

Dr. Richard Hartel
Professor of Food Engineering, University of Wisconsin-Madison

Dr. Greg Ziegler
Professor of Food Science, Penn State University

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Chocolate: Food of the Gods

- **Interactive session with chocolate**
  - Where does chocolate come from?
  - How is it made?
  - How are chocolates different?
  - Some of the science in chocolate

- **Taste the Hershey Kiss**
  - Describe what you taste.
  - What memories does it invoke?
  - How do you know it’s chocolate?

www.hersheys.com/trickortreats/activities/costume-kiss.asp
Chocolate Standard of Identity

- **Must meet FDA Standard of Identity**
  - Must contain a minimum amount of components from the cocoa bean
- **Controlled ingredients**
  - Only cocoa butter and butter oil permitted fats
  - Chocolate flavor from chocolate liquor only
  - Only “nutritive carbohydrate sweeteners” permitted
  - No flavors simulating chocolate or dairy permitted

Chocolate: *Theobroma Cacao*  
*Food of the Gods*
Cacao Production

- Cacao trees grown in tropical climates
  - Within 15° of equator
- Sources
  - Africa: Ivory Coast, Ghana
  - Indonesia/Malaysia
  - Brazil
- Cocoa beans grow inside pods
  - Harvested, beans removed, fermented, dried

Ready for Harvest
Harvesting

Pod Opening
Pod and Beans

Fermenting
Drying

Cocoa Beans
Cocoa Bean Processing

Cocoa beans
- Roasting
- Winnowing
- Pressing
- Grinding

Cocoa butter
Cocoa powder
Chocolate liquor

Shells (10-18%)
Nibs

Chocolate Liquor: Food of the Gods

- Ground cocoa nibs containing a mixture of cocoa solids and cocoa butter
- The primary ingredient for making chocolate

Taste the chocolate liquor (Baker’s chocolate)
Chocolate Liquor Composition

• Nibs (ground)
  – 48-57% fat - cocoa butter
  – 2-3.5% water
  – 40-50% cocoa solids
    • starch, fiber and gums, etc.

• Alkaloids
  – 0.8 - 1.3% theobromine
  – ≈0.2% caffeine (some people say there is no caffeine in chocolate)

Alkaloids

• Theobromine and caffeine are related methylxanthine compounds

\[
\text{Theobromine} \quad \text{Caffeine}
\]

• But they have very different physiological effects
Alkaloids

• Theobromine
  – Gentle, mild effect
  – Long lasting (6 hr.)
  – Increases well-being
  – Mild anti-depressant
  – Stimulates cardiovascular and muscular systems
  – Mild effect on central nervous system
  – Not addictive
  – Mild diuretic

• Caffeine
  – Strong, intense effect
  – Short term (2-3 hr.)
  – Increases alertness
  – Increases emotional stress
  – Stimulates cardiovascular and respiratory systems
  – Strong effect on central nervous system
  – Addictive
  – Strong diuretic

www.xocoatl.org/caffeine.htm

Audience Survey Question

Why shouldn’t you let your dog eat chocolate?

a) It causes them to become seriously ill
b) That’s less chocolate for us
c) Dogs metabolize theobromine very slowly
d) All of the above

www.hersheys.com/nutrition/theobromine.asp
Chocolate

“In 1847, an English company introduced the first solid eating chocolate made by combining melted cocoa butter with sugar and cocoa powder. This chocolate had a smooth, velvety texture and quickly replaced the old coarse-grained chocolate …”

Chocolate liquor
Cocoa butter
Sucrose
Milk source (optional)
Lecithin
Vanillin

Dark Chocolate
Example Compositions

<table>
<thead>
<tr>
<th></th>
<th>• Minimum Semi-sweet</th>
<th>• 70% Bittersweet</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sugar</td>
<td>50.4%</td>
<td>29.4%</td>
</tr>
<tr>
<td>Chocolate liquor</td>
<td>35.0%</td>
<td>70.0%</td>
</tr>
<tr>
<td>Cocoa butter</td>
<td>14.0%</td>
<td>--</td>
</tr>
<tr>
<td>Lecithin</td>
<td>0.3%</td>
<td>0.3%</td>
</tr>
<tr>
<td>Vanillin</td>
<td>0.1%</td>
<td>0.3%</td>
</tr>
</tbody>
</table>

Compare Hershey Special Dark vs. Lindt 70%
(save half the Lindt for later)
70% Cocoa

- By cocoa, manufacturers are counting all the chocolate liquor and extra cocoa butter added to the bar.
- 70% cocoa means that there’s only about 29.5% sugar in the bar (the rest is vanilla and lecithin)
- It tastes really chocolatey

Chocolate Processing

- Mix
- Refine
- Conch
- Temper
- Panning
- Enrobed bar
- Molded bar
Chocolate/Coating Structure

- **About 60-70% dispersed particles**
  - Sugar crystals, cocoa solids, milk powder
- **30-35% fat (cocoa butter or PKO)**
  - Melted chocolate, fat is liquid
  - Solidified chocolate, fat is partially crystalline
- **About 0.5% water**
  - Probably associated with sugar crystals and cocoa solids
- **About 0.2-0.3% lecithin**
  - Coats sugar particles and cocoa solids, the hydrophilic components

Composite Image of Chocolate

**Confocal Microscopy**

- Dark green: sugar crystals
- Bright green: milk protein
- Red: cocoa solids
- Blue: liquid fat
- Black: sugar crystals

From Mark Auty, DPC, Moorepark
**What is White Chocolate?**

**a)** Dark chocolate gone incognito  
**b)** Dark chocolate with white color added  
**c)** Chocolate without nonfat cocoa solids  
**d)** Milky milk chocolate

---

**White Chocolate**

- Contains everything except the cocoa liquor  
- Chocolate flavor comes only from the cocoa

**What is predominant flavor?**
Important Properties of Chocolate

1. Particle size (fineness)
2. Flavor
3. Viscosity
4. Fat phase properties
   - Tempering
   - Melting properties
5. Polyphenols

Cocoa Butter Melting

- Draw the melting profile of cocoa butter

![Melting profile of cocoa butter graph](image)
Wax in your Chocolate?

• Why do some chocolates have a waxy aftertaste? Is it because chocolate makers add wax to their chocolate?

- Wax is not allowed in chocolate under the Standard of Identity!!
- There are NO chocolate manufacturers that add wax to their chocolate!!

Paraffin wax is mostly found as a white, odorless, tasteless, waxy solid, with a typical melting point between about 47 °C to 64 °C (116.6° F to 147.2° F).

en.wikipedia.org/wiki/Paraffin

Cocoa Butter Melting Profiles

• Cocoa butters from different sources have slightly different melting profiles

![Cocoa Butter Melting Profiles](image-url)
Important Properties of Chocolate

1. Particle size (fineness)
2. Flavor
3. Viscosity
4. Fat phase properties
   - Tempering
   - Melting properties
5. Polyphenols

Lipid Crystallization

Liquid structures form in lipid melts as temperature decreases below melting point.
Polymorphism

• **Polymorphic structures**
  – molecules may take more than one crystal form
  – different lattice structures
    • TAG can be oriented at different angles

![Polymorphic structures diagram]

• Or in different lengths (double or triple packing)

Monotropic Polymorphism

![Monotropic Polymorphism diagram]
## Cocoa Butter Polymorphism

<table>
<thead>
<tr>
<th>Polymorph</th>
<th>Melting Point</th>
<th>$\Delta H$ (cal/g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\gamma$</td>
<td>17.3°C</td>
<td>-</td>
</tr>
<tr>
<td>$\alpha$</td>
<td>23.3</td>
<td>20.6</td>
</tr>
<tr>
<td>$\beta'_2$</td>
<td>25.5</td>
<td>26.9</td>
</tr>
<tr>
<td>$\beta'_1$</td>
<td>27.5</td>
<td>28.1</td>
</tr>
<tr>
<td>$\beta_2$</td>
<td>33.8</td>
<td>32.7</td>
</tr>
<tr>
<td>$\beta_1$</td>
<td>36.3</td>
<td>35.4</td>
</tr>
</tbody>
</table>

Wille and Lutton, 1966)

## Cocoa Butter

One stable $\beta$ seed
Monotropic Polymorphism

![Diagram showing Monotropic Polymorphism]

**Temperature**
- \( T_{m} - \beta \)
- \( T_{m} - \beta' \)
- \( T_{m} - \alpha \)

**Crystallization Rates**
- \( \alpha \): Crystallizes very rapidly
- \( \beta \): Crystallizes more rapidly
- \( \beta' \): Crystallizes very slowly

Tempering

1. Melt
2. Cool - no crystallization
3. Form mix of crystals
4. Melt out unstable polymorphs

![Tempering Process Diagram]

**Temperature**
- 50°C
- 32°C
- 30-32°C

**Time**
- 1
- 2
- 3
- 4

1-2% crystals
Tempering

• Critical to making fine chocolate
  – Provides numerous stable β polymorph seeds to set the remaining cocoa butter as it solidifies
  – Typically thought that 1-2% of the cocoa butter mass should be seed crystals

Tempering
Start fat crystallization

Cooling Tunnel
Continue fat crystallization

Poorly Tempered Chocolate

![Diagram showing CB Seeds in Fat (%) vs. Light Color Area (%)]

![Diagram showing Marble Temp vs. CB Seeds in Fat (%) and Light Color Area (%)]
Bloom Development w/o Tempering

<table>
<thead>
<tr>
<th></th>
<th>Before Bloom</th>
<th>Light Brown</th>
<th>Dark Brown</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sugar (%)</strong></td>
<td>34</td>
<td>43</td>
<td>34</td>
</tr>
<tr>
<td><strong>Fat (%)</strong></td>
<td>38</td>
<td>21</td>
<td>39</td>
</tr>
</tbody>
</table>

From Mark Auty, DPC, Moorepark

Cocoa Butter

1. Without Seeds
2. One
3. 0.00055% seeds
4. 0.027% seeds
5. 0.137% seeds
Cocoa Butter

1. Without Seeds
2. One seed
3. 0.00055% seeds
4. 0.027
5. 0.137% seeds

CB Crystallization vs Bloom

seeds amount increased, β crystallization took less time to reach upper level of solid fat content and the size became smaller – the result, a smooth surface.
Chocolate Chemistry: Lessons Learned

• Chocolate used to be used as “money” and it grows on trees, so money really does grow on trees.
• Chocolate is a vegetable so it’s good for you.
• Be sure to temper your chocolate correctly if you want nice shiny pieces.

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