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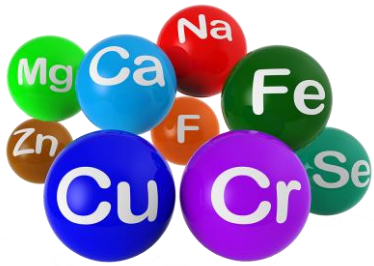


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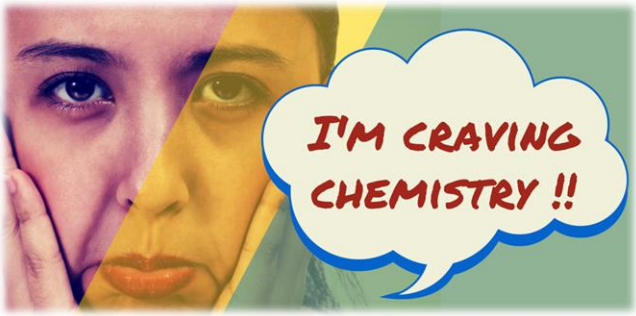


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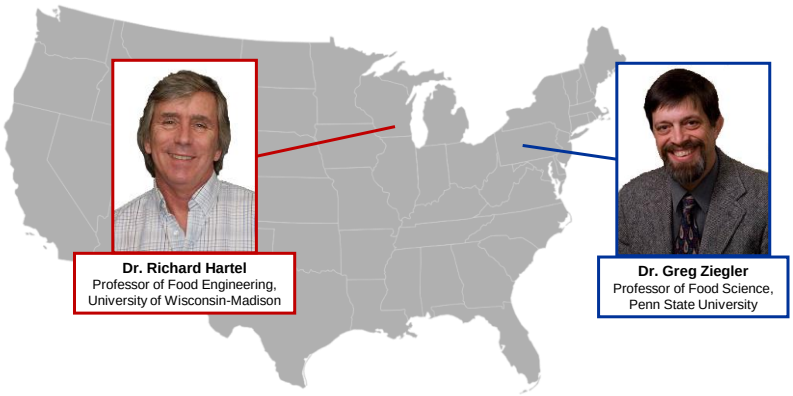
*"**Sweet Science:** Chocolate Chemistry for Valentine's Day"*

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# Chocolate Chemistry

**Dr. Rich Hartel**
**Professor of Food Engineering**
**UW-Madison**

**With Thanks To:**

**Ed Seguine**
**Mars, Inc.**

**Adam Lechter**
**ADM Cocoa**

## 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?**


# 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

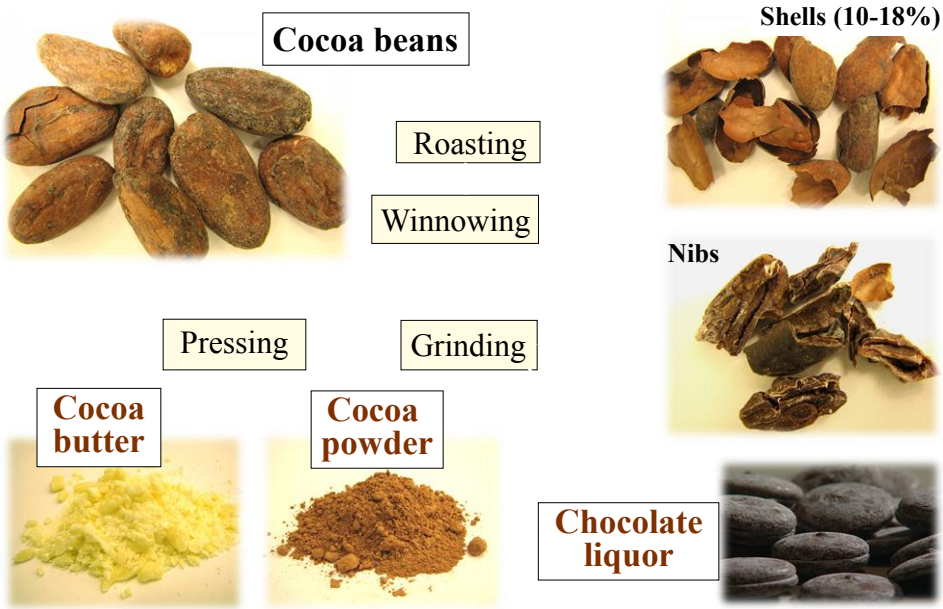
## Pod and Beans

## Fermenting

## Drying


## Cocoa Beans

# Cocoa Bean Processing




# 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)**

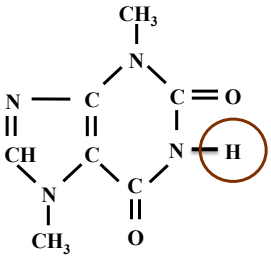
# Chocolate Liquor Composition

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

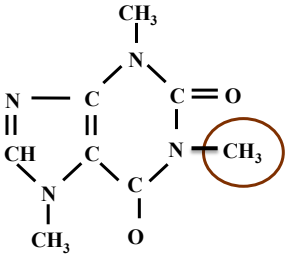
- **Alkaloids**
  - 0.8 - 1.3% theobromine
  - ≈0.2% caffeine (some people say there is no caffeine in chocolate)

# Alkaloids

- Theobromine and caffeine are related methylxanthine compounds



**Theobromine**



**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.htmc**

## Audience Survey Question

ANSWER WITH THE CORRECT LETTER IN THE QUESTIONS BOX


**Why shouldn't you let your dog eat chocolate?**

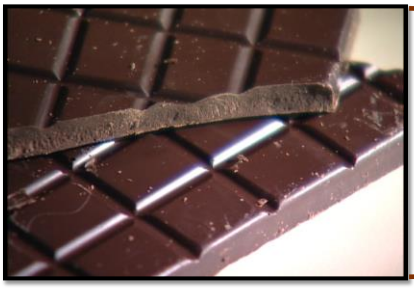
**a)** It causes them to become seriously ill
**b)** That's less chocolate for us
**c)** Dogs metabolize theobromine very slowly
**d)** All of the above

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

30

# 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

- Minimum Semi-sweet

| | |
|---|---|
| 50.4% | Sugar |
| 35.0% | Chocolate liquor |
| 14.0% | Cocoa butter |
| 0.3% | Lecithin |
| 0.1% | Vanillin |

- 70% Bittersweet

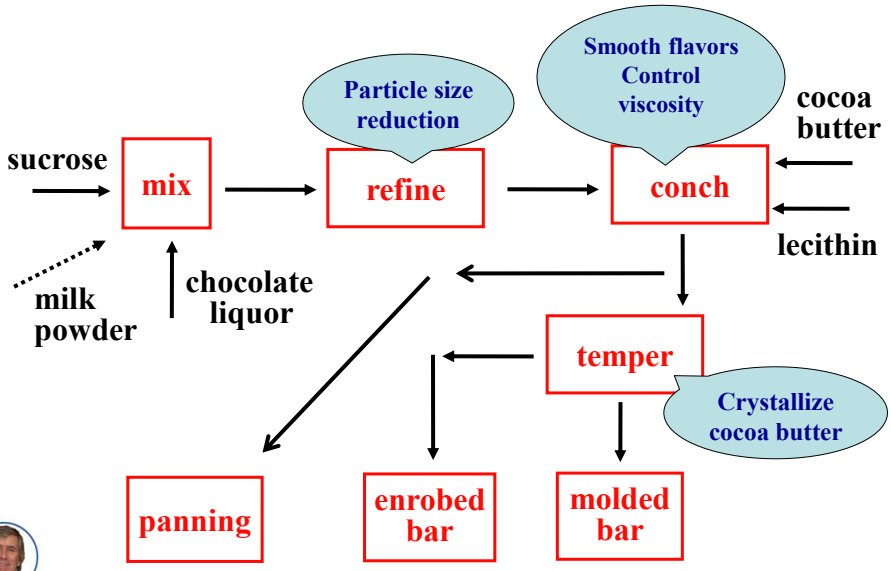
| | |
|---|---|
| 29.4% | Sugar |
| 70.0% | Chocolate liquor |
| -- | Cocoa butter |
| 0.3% | Lecithin |
| 0.3% | Vanilla |


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

# 70% Cocoa

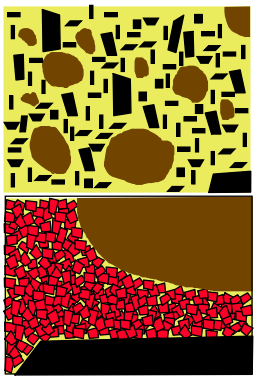
- By cocoa, manufacturers are counting all the chocolate liquor and extra cocoa butter added to the bar.
- 70% cocoa means that there's only about 29.5% sugar in the bar (the rest is vanilla and lecithin)
- It tastes really chocolatey


# Chocolate Processing



# 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**

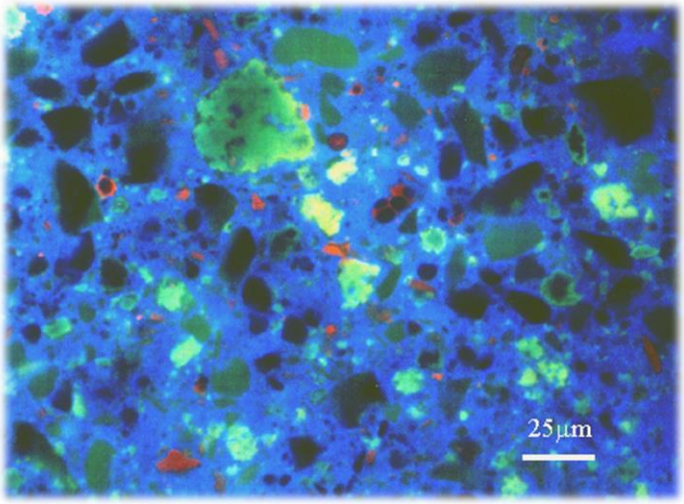
**Dark green**
**- sugar crystals**

**Bright green**
**- milk protein**

**Red**
**- cocoa solids**

**Blue**
**- liquid fat**

**Black**
**- sugar crystals**




**From Mark Auty, DPC, Moorepark**

## Audience Survey Question

ANSWER WITH THE CORRECT LETTER IN THE QUESTIONS BOX

**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

37

# White Chocolate

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

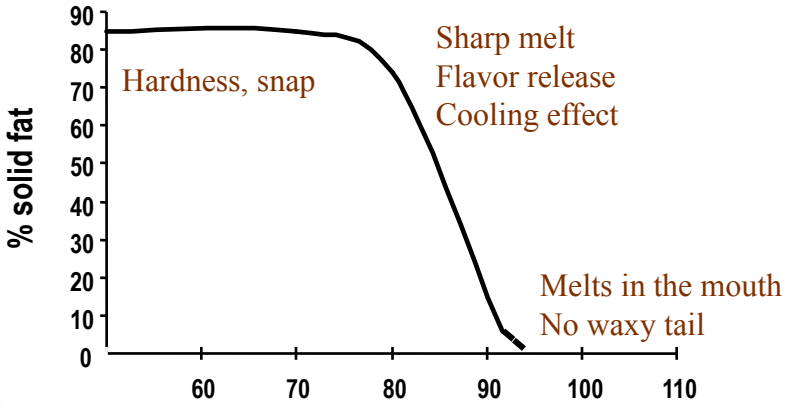
**What is predominant flavor?**

# 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




# Wax in your Chocolate?

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

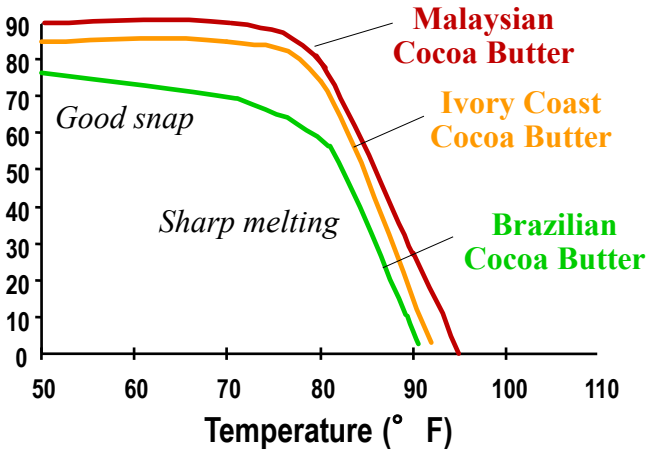
**- Wax is not allowed in chocolate under the Standard of Identity!!**
**- There are NO chocolate manufacturers that add wax to their chocolate!!**

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

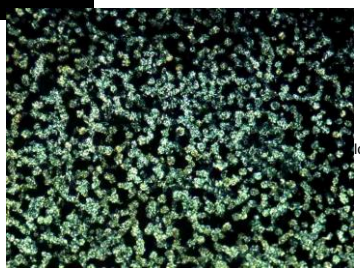


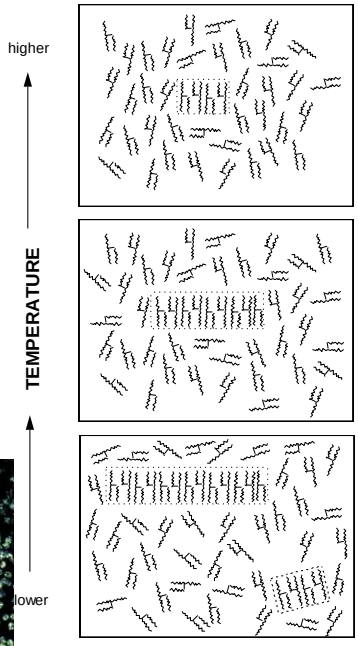

# Important Properties of Chocolate

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



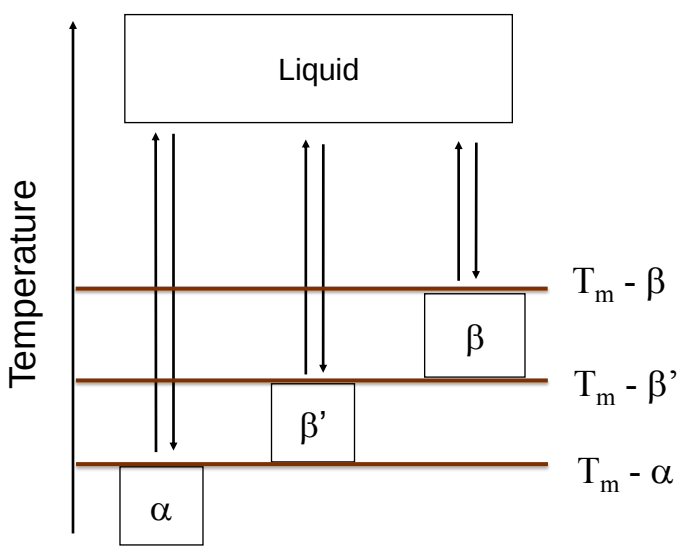



# Polymorphism

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

    - Or in different lengths (double or triple

# Monotropic Polymorphism




# Cocoa Butter Polymorphism

| Polymorph | Melting Point | ΔH (cal/g) |
|---|---|---|
| $\gamma$ I | 17.3° C | - |
| $\alpha$ II | 23.3 | 20.6 |
| $\beta'_2$ III | 25.5 | 26.9 |
| $\beta'_1$ IV | 27.5 | 28.1 |
| $\beta_2$ V | 33.8 | 32.7 |
| $\beta_1$ VI | 36.3 | 35.4 |

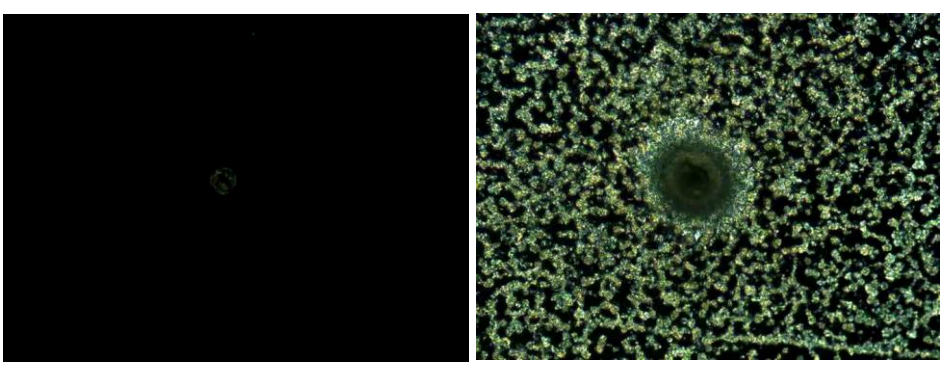
Desired form in chocolate

Form associated with bloom

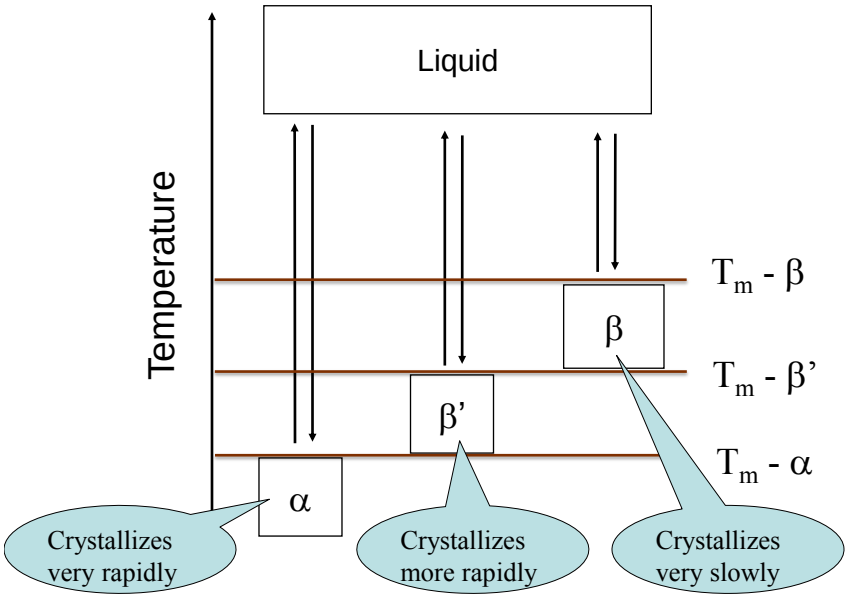
Wille and Lutton, 1966)

# Cocoa Butter

One stable β seed

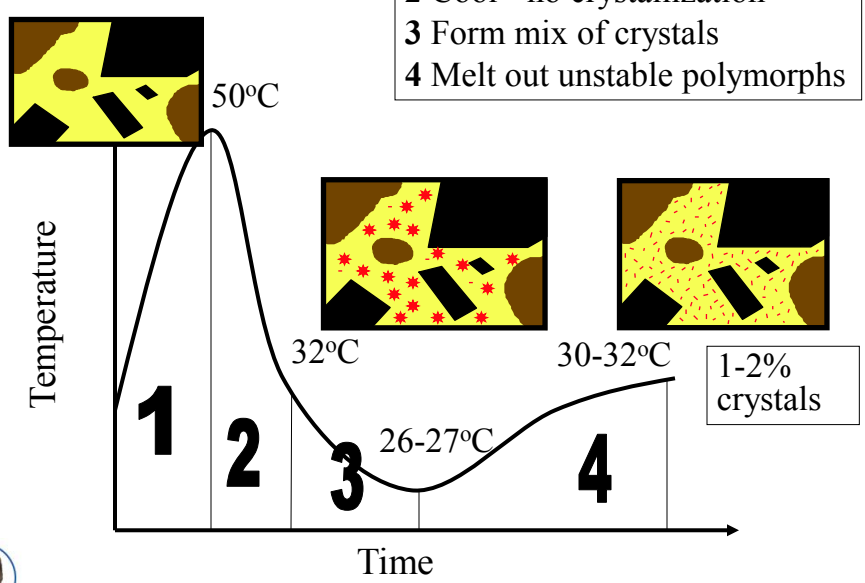


# Monotropic Polymorphism




# Tempering

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

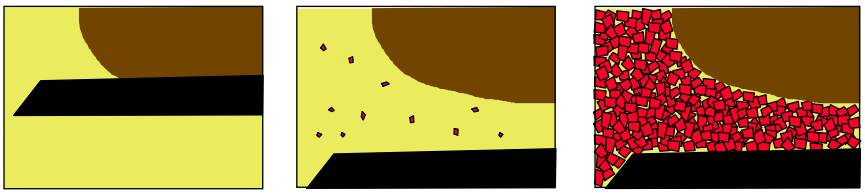



# Tempering

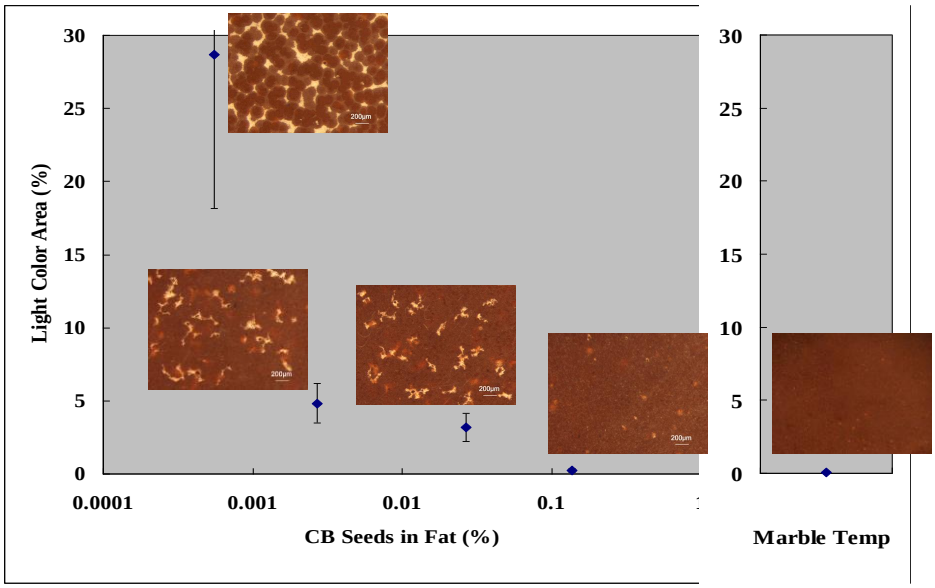
- **Critical to making fine chocolate**
  - Provides numerous stable β polymorph seeds to set the remaining cocoa butter as it solidifies
  - Typically thought that 1-2% of the cocoa butter mass should be seed crystals

Tempering
Start fat crystallization

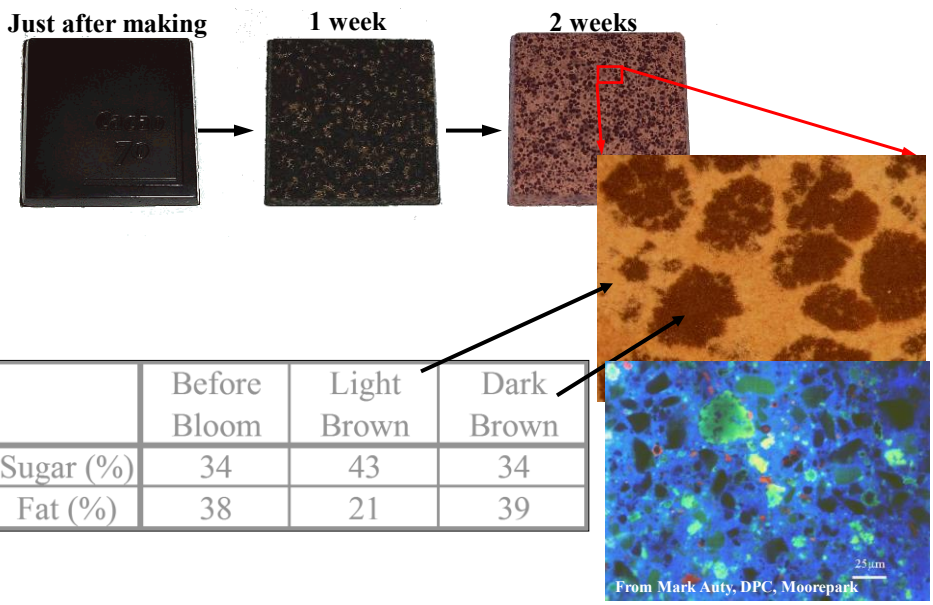
Cooling Tunnel
Continue fat crystallization



# Poorly Tempered Chocolate



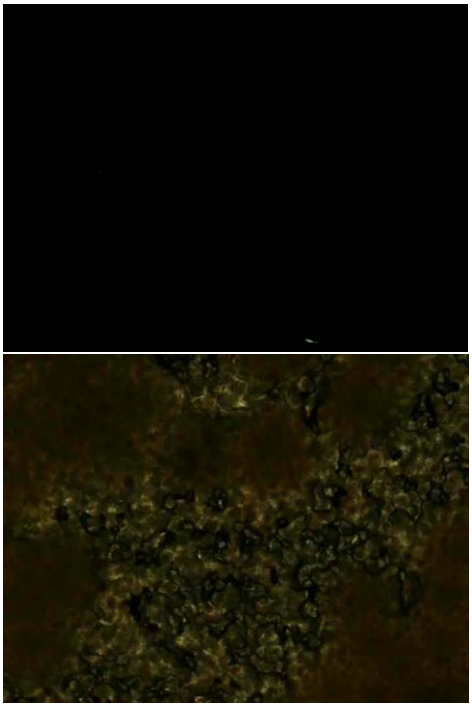
# Bloom Development w/o Tempering




| | Before Bloom | Light Brown | Dark Brown |
|---|---|---|---|
| Sugar (%) | 34 | 43 | 34 |
| Fat (%) | 38 | 21 | 39 |

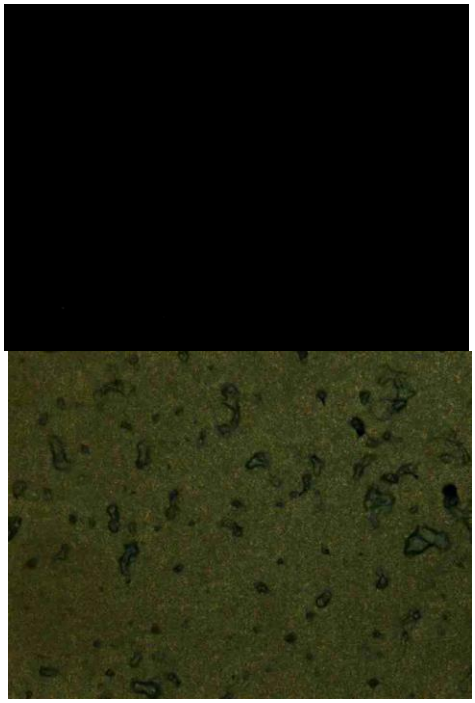
# Cocoa Butter

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



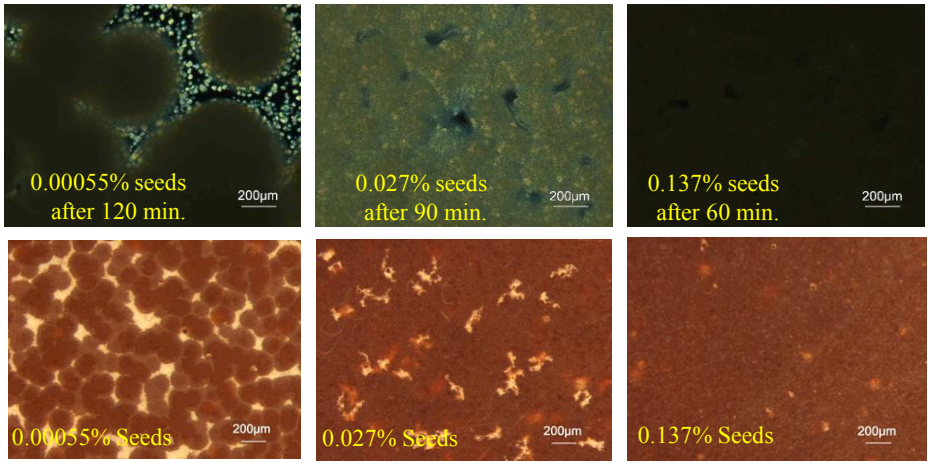
# Cocoa Butter

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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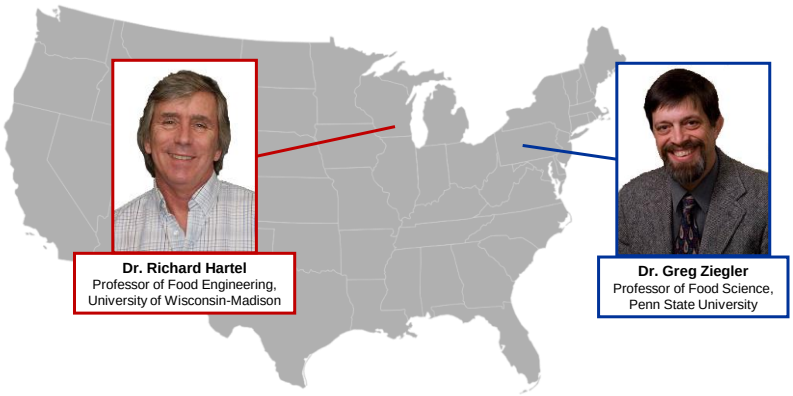


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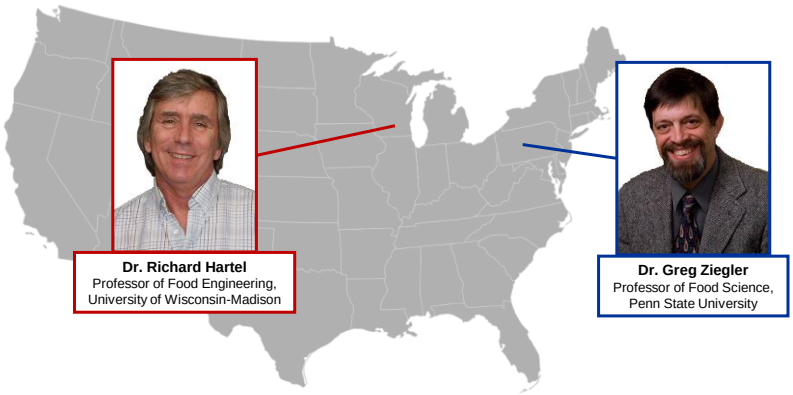


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Amy Naylor,
Professor of Chemistry
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