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Type them into questions box!

“Why am I muted?”
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Carolyn Virca
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The Chemistry of Chocolate and Desire

Bryan Guthrie
Corporate Research Fellow, Cargill

Michael Tunick
Assistant Clinical Professor, Culinary Arts & Food Science, Drexel University

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Michael H. Tunick
Center for Food & Hospitality Management
Drexel University, Philadelphia, PA
What Is Chocolate?

A semi-solid suspension of fine solid particles from sugar and cocoa (~70% total) in a continuous fat phase

Cocoa solids are derived from beans obtained from the fruit of *Theobroma cacao*

Origin

- Cacao previously thought to have been first domesticated in Mesoamerica
- Greatest diversity found to be in upper Amazon region
- Archaeological evidence: cacao starch grains, absorbed theobromine residues, and DNA recovered from site in southeast Ecuador
  - Dated to ~ 5,300 years ago
- Earliest evidence of *T. cacao* use in the Americas and the first unequivocal archaeological example of its pre-Columbian use in South America
- Upper Amazon region is oldest center of cacao domestication yet identified

Zarrillo et al., Nature Ecology & Evolution, Oct. 29, 2018
Manufacture


Fermentation

- Takes place in baskets, wooden boxes, or heaps stored away from light, depending on local custom

- Beans turned to ensure even fermentation

- Process lasts 5-7 days, depending on cultivar and variety
**Fermentation: First Day**

Anaerobic, exothermic reactions, temperature to 40°C

Yeast ferments sucrose, glucose, fructose

**Fermentation: Next Day**

Aeration from turning beans, temperature to 50°C

Germ within bean dies from heat, alcohol, and acetic acid
Enzymes within bean released, important for flavor
**Fermentation: Last Days**

**Yield:** 80-85% well fermented beans

Browning reactions of polyphenol with proteins and peptides produce colors characteristic of cocoa.

**Fermentation and Drying**

Help remove natural tannins and acids present
- Tannins: 5-15% of bean by weight
- Bring astringent and bitter flavor to final chocolate

Drying limits mold growth, moisture content goes from 60 to 7.5%
- Sun-drying preferred
- Artificial drying may lead to off-flavors
Audience Survey Question
ANSWER THE QUESTION ON BLUE SCREEN IN ONE MOMENT

Why is it called Baker’s Chocolate?

• It is used in baking
• It originated in the Baiker region of West Africa
• It was named after a guy named Baker
• Nobody knows

Chocolate Types

Baker’s chocolate/bitter chocolate/unsweetened chocolate: made from pure chocolate liquor (100% cacao with no sugar added)

Bittersweet chocolate: sweetened dark chocolate with sugar and cocoa butter and ≥ 35% chocolate liquor (70-100% cacao)

Semisweet chocolate: dark, sweetened chocolate made with ≥ 15% chocolate liquor
Chocolate Types

**Milk chocolate:** In US, must contain \( \geq 10\% \) chocolate liquor and 12% whole milk (usually in dried form)

- Bars of fine milk chocolate generally contain 30-45% cacao
- Cheapest can have as little as 5% cacao

**Dark chocolate:** 15-35% chocolate liquor with cocoa butter, vanilla, sugar, or other sweetener, and usually lecithin as an emulsifier

**White chocolate:** cocoa butter (\( \geq 20\% \) in US), sugar, milk powder, spices such as vanilla

Milk Chocolate

**Milk solids added**

**Milk fat:** 15-20% solid at ambient temperature

- Softens chocolate texture, used at \( \leq 30\% \) of total fat content
- Inhibits fat bloom

**Milk proteins add to perceived creaminess**
Sensory Attributes

**Appearance:** smooth, shiny, mahogany-black

**Sound:** clear and crisp snap when broken

**Touch:** should quickly start to melt in hand with no graininess in mouth

**Smell:** fruits, nuts, spices, flowers, sugar, etc.

**Taste:** bitterness with hint of acidity, sweetness with suggestion of sourness, touch of saltiness, plus characteristic flavors

---

Snap

Good, clean snap indicates high cacao content and well-tempered chocolate

Too dry if it splinters, too waxy if it resists breaking

Milk chocolate (lower levels of cocoa solids) and white chocolate (no cocoa solids) do not have the same snap

**Opposite:** crumbly
Texture

Mouthfeel and textural properties determined by unique properties of cocoa butter

Careful processing and selection of ingredients necessary to produce desirable properties

Viscosity controlled by addition of cocoa butter and surface-active ingredients (lecithin)

Particle Size

Optimization requires consideration of palate sensitivity

Product is perceived as gritty or coarse in the mouth if maximum particle size > 30 μm

Chocolate milled to maximum particle size of 20 μm will have creamier taste and texture than that with 30 μm
Cocoa Butter

Most critical raw material for chocolate

Tree, flower, pod, seed, and postharvest handling all different from those of any other food ingredient

Triglycerides primarily palmitic acid (27%), stearic acid (34%), and oleic acid (34%)

- Structure leads to unique solidification and liquefying properties
- Manufacturer can work with chocolate in ways that no other foods permit

Tempering

[Diagram showing the process of tempering chocolate, including temperatures and stages: heat to 50°C, cool to 32°C, cool again, reheat to 30°C, and finally to correct number of stable crystals, with unstable crystals melted out.]
The Six Polymorphs of Chocolate

http://www.compoundchem.com/2014/04/19/the-polymorphs-of-chocolate

Flavor and Color

Determined by processing variables and inherent characteristics of the cocoa bean

Flavor precursors develop during fermentation and primarily interact at roasting temperatures

Complex browning reactions occur during roasting

Numerous heterocyclic flavor compounds produced then contribute to the characteristic chocolate flavor
Maillard Reaction

Non-enzymatic reaction between amino acid and reducing sugar

Pyrazines

Primary odor components

~ 80 contribute to overall flavor

Most originate from α-aminoketones by Strecker degradation and Maillard reactions during roasting
Esters

Second most important odor components

- Arise from amino acids and fermentation

- Long chain esters produce undesirable fatty and waxy flavors

![Ethyl-2-methylbutanoate](image)

<table>
<thead>
<tr>
<th>Compound</th>
<th>Odor quality</th>
<th>Sensory perception</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ethyl acetate</td>
<td>Pineapple</td>
<td>Fruity</td>
</tr>
<tr>
<td>Isovaleric acid</td>
<td>Fruity</td>
<td>Fruity</td>
</tr>
<tr>
<td>Isoamyl acetate</td>
<td>Fruity, banana</td>
<td>Fruity</td>
</tr>
<tr>
<td>Benzyl acetate</td>
<td>Floral, jasmine</td>
<td>Floral</td>
</tr>
<tr>
<td>Methylphenyl acetate</td>
<td>Sweet, honey, jasmine</td>
<td>Floral</td>
</tr>
<tr>
<td>Ethylphenyl acetate</td>
<td>Fruity, sweet</td>
<td>Fruity, sweet</td>
</tr>
<tr>
<td>2-Phenylethyl acetate</td>
<td>Honey, floral</td>
<td>Floral</td>
</tr>
<tr>
<td>Ethyl butyrate</td>
<td>Pineapple</td>
<td>Fruity</td>
</tr>
<tr>
<td>Ethyl lactate</td>
<td>Fruity</td>
<td>Fruity</td>
</tr>
<tr>
<td>Diethyl succinate</td>
<td>Pleasant aroma</td>
<td>Floral</td>
</tr>
<tr>
<td>Ethyl 2-methylbutanoate</td>
<td>Fruity</td>
<td>Fruity</td>
</tr>
<tr>
<td>Ethyl 3-methylbutanoate</td>
<td>Fruity</td>
<td>Fruity</td>
</tr>
<tr>
<td>Ethyl valerate</td>
<td>Fruity, apple</td>
<td>Fruity</td>
</tr>
<tr>
<td>Ethyl hexanoate</td>
<td>Fruity</td>
<td>Fruity</td>
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<td>Ethyl octanoate</td>
<td>Fruity, floral</td>
<td>Fruity, floral</td>
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<tr>
<td>Ethyl decanoate</td>
<td>Pear, grape</td>
<td>Fruity, floral</td>
</tr>
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<td>Ethyl laurate</td>
<td>Fruity, floral</td>
<td>Fruity, floral</td>
</tr>
<tr>
<td>Isoamyl benzoxate</td>
<td>Balsam, sweet</td>
<td>Floral</td>
</tr>
<tr>
<td>Methyln salicylate</td>
<td>Bitter-almond</td>
<td>Nutty</td>
</tr>
<tr>
<td>Methyl cinnamate</td>
<td>Balsam, strawberry</td>
<td>Sweet, cinnamon-like, green chocolate</td>
</tr>
<tr>
<td>Ethyl cinnamate</td>
<td>Sweet</td>
<td>Sweet, cinnamon-like, green chocolate</td>
</tr>
</tbody>
</table>

Alcohols

- Arise during fermentation from microbial activity

- May also result from heat degradation of amino acids

- 2-phenylethanol: most odor-active compound in dried and fermented cocoas

![Alcohols](image)
Aldehydes and Ketones

Formed during fermentation

Aldehydes also arise from Strecker degradation of amino acids during roasting

- Needed for pyrazine formation

2-phenylacetaldehyde

Acids

3-Methylbutyric acid

Acetic acid most odor-active

Short chain acids mostly removed during processing

Lead to undesirable odors
Furanones and Pyrones

Produced by degradation of monosaccharides during drying and roasting

• Confer pleasant caramel notes and enhance flavor impression
• Destroyed during alkalization

\[
\begin{align*}
\text{Furaneol} & \quad \text{Maltol} \\
\end{align*}
\]

Pyrrole

2-Acetyl-1-pyrrole produced during drying and roasting via Maillard reactions and Strecker degradation, starting from proline

• Confers caramel, chocolate, and roasted desirable notes

\[
\begin{align*}
\text{Proline} & \quad \text{2-Acetyl-1-pyrrole} \\
\end{align*}
\]
Other Compounds

**Alkaloids**, including theobromine (3,7-dimethylxanthine) and caffeine (1,3,7-trimethylxanthine)
- Bitter taste

**Polyphenols in 3 main groups**: catechins (flavan-3-ols), anthocyanins, and proanthocyanidins
- Astringent and bitter tastes

---

## Cravings

Most craved substance in US *(Michener and Rozin, 1994; Osman et al., 2006)*

Effects attributed to texture, sweetness, fat, aroma, and specific compounds

Xanthines implicated in cravings

*Physiol Behav* 1994, 56:419; *Appetite* 2006, 47:290
What happens in Japan on Valentine’s Day?

- Men give chocolate to women
- Women give chocolate to men
- Adults give chocolate to children
- Children give chocolate to their parents
- Nothing – The Japanese don’t celebrate the day

Methylxanthines in Cocoa

![Caffeine](image1.png)
![Theobromine](image2.png)

Caffeine metabolite
Theobromine

From Greek θεός (god) + βρῶμα (food)

100 g milk chocolate contains ~150 mg

100 g very dark chocolate contains ≤ 440 mg

(Nehlig, 2013)

Significant effects (mood and behavior changes) not seen below 560 mg theobromine in most people (Smit et al., 2004)

Caffeine

From French café (coffee)

100 g milk chocolate contains ~20 mg

100 g dark chocolate contains ~43 mg

White chocolate has none

Increases alertness, mental energy, and cognitive and psychomotor performance

• Also small increase in feelings of well-being
Caffeine’s Mechanism of Action

**Adenosine**: central nervous system neuromodulator with specific receptors

Upon binding to receptors, neural activity slows, creating sleepiness

- Dilates blood vessels to ensure good oxygenation during sleep
- Caffeine acts as adenosine-receptor antagonist
  - Binds to same receptors but without reducing neural activity
  - Fewer receptors available to natural braking action of adenosine, and neural activity increases

Caffeine’s Mechanism of Action

Causes pituitary gland to secrete hormones that cause adrenal glands to produce more adrenalin

- Increases energy level and alertness
- Increases production of dopamine in brain’s pleasure circuits
Phenylethylamine

Related to amphetamines, releases dopamine

Derived from phenylalanine in body or by microbes

Typically 50-100 mg in 100 g chocolate bar

Quickly metabolized by monoamine oxidase B

Anandamide

From Sanskrit ananda (bliss) + amide

First described in 1992

50 μg/100 g cocoa bean (Nehlig, 2013)

Metabolite of arachidonic acid (20:4)

Fatty acid neurotransmitter

Endocannabinoid
Anandamide Experiments

Neural receptors same ones to which THC binds

**Hypothesis:** endogenous cannabinoid system plays role in regulation of appetite and food intake, involved in reward processes that mediate incentive or hedonic value of food

Experiments conducted on rats injected with anandamide and fed sugar and quinine solutions

Anandamide Results

Anandamide specifically amplifies hedonic impact of sweetness (prototypical sensory pleasure)

Rewarding and euphoric effects of exogenous cannabinoid drugs (such as THC) mediated by same endocannabinoid hedonic hotspot that amplifies taste ‘liking’

Mahler et al., 2007
Anandamide

Might contribute to feeling of well-being

- But rapidly broken down by fatty acid amide hydrolase
- > 30 kg chocolate to experience effects comparable to 1 dose of cannabis

Magnesium

Deficiency implicated in major depression (Eby and Eby, 2006)

Craving proposed as response to Mg deficit

100 g milk chocolate contains ~63 mg Mg

100 g dark chocolate contains ~146 mg Mg

Foods high in Mg not craved, do not satisfy craving for chocolate (Parker et al., 2006)
Possibilities

Simultaneous activation of dopamine and opioid systems seen with ingestion of high fat/sugar foods

Similar to effects by dopamine agonists (amphetamine, cocaine) and opioid agonists (heroin, morphine)

Dopamines

Chocolate may interact with some neurotransmitter systems such as dopamine (chocolate contains dopamine precursor tyrosine), serotonin, and endorphins (contained in cocoa and chocolate)

• Contribute to appetite, reward and mood regulation

Contribution of dopaminergic system to chocolate craving and eating likely to be general, not chocolate specific
Opioids

Intake of sweet food increased by opiate agonists and decreased by opiate antagonists

Opioid system plays role in palatability of preferred foods

- Endorphins released during eating could enhance pleasure of eating
- Chocolate stimulates endorphin release

Opioids can stimulate immediate release of beta-endorphin in hypothalamus
- Produces analgesic effect

Serotonin

After ingestion of carbohydrates, brain serotonin concentrations rise only when protein component of meal < 2%

Chocolate contains 5% of calorie content as protein
- Negates any serotonin effect

Extreme dietary manipulations of tryptophan (serotonin precursor) result in physiological changes
- Too slow to account for mood effects described during or soon after eating chocolate
Human Study

Tested on 280 passersby given 12.5 g chocolate

<table>
<thead>
<tr>
<th>Chocolate type</th>
<th>% Cocoa</th>
<th>Sugar (g)</th>
<th>Fat (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lindt® white</td>
<td>0</td>
<td>7.0</td>
<td>4.5</td>
</tr>
<tr>
<td>Lindt® milk</td>
<td>38</td>
<td>7.0</td>
<td>3.9</td>
</tr>
<tr>
<td>Russell Stover®</td>
<td>60</td>
<td>7.0^</td>
<td>3.7</td>
</tr>
<tr>
<td>Lindt® dark</td>
<td>70</td>
<td>3.5</td>
<td>5.5</td>
</tr>
<tr>
<td>Lindt® dark</td>
<td>80</td>
<td>1.6</td>
<td>6.9</td>
</tr>
</tbody>
</table>

Content is per 12.5 g piece of chocolate.
^ As sorbitol.

Nasser et al., 2011

Human Study

Tasting had measurable psychoactive effects, associated with desire to consume more

Desire proportional to sugar and fat contents and percent of cocoa

Sample with sorbitol instead of sucrose produced same results as 0 and 38% sucrose samples (all had 56% sugar)

Binding to sweet receptor (rather than taste of sugar) plays role in triggering psychoactive effects
Men vs. Women

Men had significantly lower chocolate craving and liking scores

When asked how much more chocolate they would like to consume, men asked for 4 pieces and women 3 pieces

Women concerned with weight?

Explanation of Craving

Composite sensory properties more likely to play prominent role in chocolate liking or craving

If caloric deficit motivates chocolate craving, both milk chocolate and white chocolate should appeal equally, but don’t

If psychoactive substances or Mg deficit motivate chocolate craving, both milk chocolate and unsweetened cocoa powder should appeal equally, but don’t

Probably learned emotion
**Aphrodisiac**

**Definition:** substance that increases libido

Derived from Aphrodite, Greek goddess of love

Aztecs first to attribute cocoa bean and sexual desire

Idea brought to Europe by Spanish

Eight Deer Jaguar Claw receiving chocolate from bride, 13 Serpent

---

**Desirable Compounds**

Amounts of **phenylethylamine**, **anandamide**, etc., in chocolate too small to have any measurable effect on desire

Compounds broken down too fast

Phenethylamine

Anandamide
Aphrodisiac Qualities

Studies find no direct link between chocolate consumption and heightened sexual arousal

Aphrodisiac qualities probably psychological and not physiological

Books For Further Reading


The Chemistry of Chocolate and Desire

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Conclusions and Final Thoughts

Compounds in chocolate not present in high enough concentrations (theobromine), do not contribute to craving (caffeine, Mg), broken down too quickly (phenylethylamine, anandamide), or too slowly (carbohydrates/serotonin) to produce aphrodisiac effect.

Chocolate cravings probably stem from flavor, texture, aroma, and psychology more than specific compounds.

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