Sugar Reduction: How to Formulate with Less Sugar While Maintaining Sugar-like Properties

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When it comes the topic of formulating with less sugars, have you ever wondered how to do it ....

- Without sugar?
- With something that is better for you?
- With something from nature?
- Or even without adding any ingredient?

I will focus today on how to make reduced sugar foods sweeter, naturally and simply.
Outline

- Taste physiology and neuroscience
  What is it and why does it matter?

- Make things taste sweeter, naturally
  How to reduce sugars in foods with natural non caloric high potency and bulk sweeteners?

- Make things taste sweeter, simply
  How to make foods taste even sweeter with cross-modal correspondences?

- Take-home message
  “The taste physiology of today, is the food ingredients of tomorrow.”
Re-Defining “Flavor” = Taste + Smell + More

- Taste (5+ primary)
- Smell (aroma)
- Trigeminal sensations (chemical irritants and temperature)
- Touch and Vision (“Seeing the flavor”. Acree, 2013)
Taste Perception Wiring System

The tongue has two nerve systems, each consist of 5,000 fibers, and each of which is coded, that is some fiber is sweet-specific. (DuBois, 2011)
Taste Buds

Taste buds are located on three kinds of papillae on human tongue. The number of taste buds on human tongue varies by a factor of 100.
Taste Cells

A taste bud is a cluster of 100 elongated taste cells like an orange segment. Each taste bud cell is taste-specific (One taste, one cell class, Zuker, 2011). There is integration of gustatory information from different taste cells (Sternini, 2013), that is “sensory processing circuitry” (Bigiani, 2011).
A tastant such as a sweetener in the saliva only touches the receptors at the tip of the taste bud cell. After it excites the taste bud cell, an electrical signal is carried to the synapse then to the brain. Sweet taste corresponds to a “hot spot” in the brain, separate from other primary tastes. (Zuker, 2011)
Taste Receptors

Taste receptors had been identified during the rapid advances of taste physiology and neuroscience in the past 15 years (NIZO, 2011)

- **Sweetness**: 1 Receptor: T1R2/T1R3. Family: GPCR. 2001.
- **Umami**: 1 Receptor: T1R1/T1R3. Family: GPCR. 2002.
- **Saltiness**: “Receptor”: ENaC. Family: Na Channel. 2010.
- **“Fat”**: Receptors: CD36, GPR120, FA1. Family: Several GPCR
- **“Calcium”**: Receptor: CaR. Family: GPCR
- **“Water”**: Receptor: Aquaporins. Family: Channel
Sweet Taste Receptor

Sugar Reduction Roadmap

How to formulate:
1. Always start with natural high potency sweeteners.
2. Make it sweeter and more like sugar with natural non/low caloric bulk sweeteners. Use bulking agents to compensate for missing functional properties from sugar.
3. Lastly, make it even sweeter with cross-modal correspondences.

If: Beverages
Then:
1. High Potency Sweeteners,
2. Non/Low Caloric Bulk Sweeteners, if needed

If: Foods
Then:
1. High Potency Sweeteners,
2A. Non/Low Caloric Bulk Sweeteners,
2B. Bulking Agents

If: Sweeter
Then:
3. Cross-Modal Correspondences
Make Things Taste Sweeter, **Naturally**

- Keep it natural
  - Natural high potency sweeteners
    - Stevia extract
    - Monk fruit extract
  - Natural non caloric bulk sweeteners
    - Erythritol

- Less is More!
  - Blend them, each at low usage level
  - To achieve maximum sweetness yet with minimal off flavors and lowest cost in use.
High Potency Sweeteners

Technologies go from “Emerging” (discovered but not yet commercialized) to “Pacing” (first to market sets the pace) and finally to “Mature” (patent expired and technology commodititized) (AD Little, 2000s, Alex Woo, W2O, 2014)
Stevia Extract
(Multiple suppliers’ websites)

- Natural
- Non caloric
- GRAS: FDA No Objection Letter
- Purity: RA 50 to RA100
- 300X as sweet as sugar
- Heat and pH (>3) Stable
- Non GMO
- Kosher & Halal Certified available
- 0.02% in beverages = about 6% Sugar Equivalence
- Most commonly labeled as “stevia extract”
Monk Fruit Extract
(Multiple suppliers’ websites)

- Natural
- Non caloric
- GRAS FDA No Objection Letter 2010, not yet in EU

Purity: Up to Mogroside-V 55%
- 150X as sweet as sugar
- Heat Stable
- Non GMO
- Kosher Certified
- 0.01% in beverages = about 2% Sugar Equivalence
- Labeled as “monk fruit extract”
Monatin
An unique natural amino acid that recently came alive

- Being developed by an ingredient technology leader
- Amino acid extracted from a South African plant Sclerochiton ilicifolius (root)
- 3,000x sugar @ 5% SE (R,R-form)
- Unique temporal profile: quick on set and no lingering, no bitter metallic, no astringent after taste (Fry, 2012)
- UV instability?
- Not yet approved anywhere
Non/low Caloric Bulk Sweeteners
(Alex Woo, W2O 2014)

Emerging

Pacing

Mature

D-Ribose

Erythritol

Artificial Polyols

L-Arabinose

Xylitol

Isomaltulose

D-Psicose

Tagatose

Trehalose
Erythritol

One of the two natural non-caloric and cost-effective bulk sweeteners that is not “sugar”
(Multiple suppliers’ websites)

- Found in fruits and vegetables
- Made by fermentation
- Highest digestive tolerance amongst all polyols
- Non caloric (0-0.2 calorie per gram)
- Non GMO possible
- 65% as sweet as sugar
- 3.5% limit in beverages USA, GMP levels in many countries
- Labeled as “Erythritol”
Why do we need “bulking agents”, or more accurately “sugar substitute”?

- Sugar is not only sweet
- It is also multi-functional in foods
  - Beverage
    - Flavor enhancement/release
    - Mouthfeel
  - Bakery, dairy and confections
    - Flavor and appearance: flavor and brown color (Maillard reaction and fermentation), shiny.
    - Texture: tender, moist, soft, crisp, chewy, crunch, melt, airy, fluffy, creamy, silky, sticky (Functional properties including viscosity, freezing, melting, gelation, aeration, emulsion, water binding, crystallization, surface tension, film formation, and weight/volume)
Non/low Caloric Bulking Agents
(Alex Woo, W2O 2014)

Emerging
- Oat Fibers
- Coffee Flour
- Inulin

Pacing
- Resistant Starches/Dextrins
- Gums
- Milk Protein Concentrates

Mature
- Fibers/Celluloses
- Polydextrose
- Water
Inulin

One of the most versatile natural bulking agents (Multiple suppliers’ websites)

- Fructose polymer (fructan) mostly with a terminal Glucose. High performance inulin = DP 10+
- Found in nature, extracted from chicory root
- A prebiotic dietary fiber
- Low Caloric: ~1.5 Kcal/g (2 Kcal in EU)
- GRAS
- Non GMO
- Usage level: GMP
- Labeled as “Inulin” or “chicory root fiber”
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2B. Bulking Agents

If: Sweeter
Then:  
3. Cross-Modal Correspondences
Cross-Modal Correspondences
How brain process information from different senses to form multi-sensory experiences in our daily lives (Spence, 2013)

- Smell on taste
- Trigeminal sensations on taste
- Sight on taste
- Sound on taste
Smell

Humans have 350 odor receptor genes (Hayes, 2013) operating on a pattern-recognition model (Buck and Axel, 2004) detecting 1 trillion odorants (Vosshall, Keller 2014) in a “Many-to Many” mode (Downey, 2014). We detect a smell when an odorant binds (Weak-Shape Theory) to the odor receptor (OR) expressed by olfactory sensory neuron (OSN) in the olfactory epithelium. Each OSN expresses only one type of OR, and the Axons of these OSNs project directly to the olfactory bulb (OB) (Cheetham and Belluscio, 2014).


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Smell and Taste Cross-Modal Association

This is because although the sweetness is perceived in the mouth when a sweetener in the saliva touches the receptors at the tip of the taste bud cell....
…, there is interaction between olfaction and gustation (Taylor, 2010). That is, retronasal “sweet” aroma (smell) in the nose increases the sweet perception in the mouth (taste).
Smell and Taste Cross-Modal Association

All of these sweet taste modulators (in black) are legally labeled as “natural flavor”.

Emerging
- Cell Tech - Based PAM
- Mouth Feel Agents
- Osmolytes

Pacing
- Non-Specific Enhancers
- Phantom Flavors
- Congruent Flavors

Mature
- Non-Specific Blockers
- Non-Specific Maskers
- Flavors
Smell and Taste Cross-Modal Association

“Using molecular biology to trick your taste buds is kind of novel for the food industry” (Tepper, 2013)

- Example: Fresh tomato aroma made tomato tasted sweeter (Bartoshuk, 2013)
- Example: Sugar distillate enhanced beverage sweetness, tea essence enhanced sweetness in tea (supplier literature, 2013)
- Example: Vanilla below or above aroma threshold enhances sweetness in US (various empirical reports, up to 2012) but saltiness in Japan (Spence, 2013)
Smell and Taste Cross-Modal Association

Many non-specific sweet enhancers are labeled as “natural flavor”, but the positive allosteric modulators (PAMs) would be better if they were natural. (Alex Woo, W2O 2014)
Smell and Taste Cross-Modal Association

Some FDA GRAS natural high potency sweeteners are also approved under FEMA GRAS, as “natural flavor” when used at extremely low level as sweetness enhancers (FEMA GRAS list 2013)

- Example: Thaumatin (0.5 to 1ppm. supplier literature)
- Example: Monk fruit extract (< 50ppm. suppliers’ website)
Trigeminal and Taste Cross-Modal Association

- Trigeminal on sweetness enhancement:

  - **Carbonation**, a trigeminal pain agent, reduced sweetness perception and made artificial high potency sweetener tasted more like sugar. (Sternini, 2013). Labeled as “carbonated water”.
  - Stevia was significantly more potent in **cold water** (Fry, 2011)
  - Drinking **hotter** water prior made dark chocolate tasted sweeter (Monya, 2013)
Look Mom, No Ingredient!

Vision on sweetness: (Shape Symbolism-Sub-consciously setting up sensory expectations in the minds of consumers. Spence, 2013)

- Shape (food): More **rounded shape** tended to associate with sweeter stimuli (Spence, 2013) including juices (Spence, 2013)
- Shape (food): **Round** chocolate tasted sweeter (Spence, 2013)
- Shape (Contextual): Gazing at **round shape** made 0.3% sugar tasted sweeter (Roy and Liang, 2013) and beer sweeter (Deroy, 2013)
Look Mom, No Ingredient!

- Vision on sweetness: Taste lies in the eyes of the beholders (Spence and Piqueras-Fiszman, 2014)

  - Color (contextual): Strawberry mousse 10% sweeter and more liked on a white plate than on a black plate (Adria, 2011. Spence, 2012)

  - Color (contextual): Hot chocolate tasted sweeter and more aroma in dark cream cup than in white or red cup (Spence, 2012.)

  - Color (contextual): Red room, red fruits, and red round shape objects in a “sweet room” made whisky tasted sweeter (Spence, 2013)
“Sonic Seasoning” (Spence, 2014)

Sound on sweetness: The sound of food, packaging, machine and environment can exert a profound, if often unacknowledged, role in flavor perception. (Sound Symbolism, Spence, 2012 and 2011)

- Twinkling/Higher pitches enhances sweetness in toffee and lower tones emphasize bitterness: Biological basis: Tongue curls upward= higher pitches= draw in sweeter foods. (Crisinel, 2012) (Spence, 2013)

- Higher frequency sounds pair well with sweet wine (Burzynska, 2013)
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If: Sweeter
Then:
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Take-Home Messages:

- Can reduce sugars in foods with high potency and bulk sweeteners, *naturally*

- Can make them taste even sweeter with cross-modal correspondences, *simply*

- “The physiology of today, is the medicine of tomorrow.” (Ernest Starling 1866-1927. Nobel Prize and discoverer of the first hormone.)

“The taste physiology of today, is the food ingredients of tomorrow.” (Alex Woo, W2O Food Innovation, 2014)