Simply Sweet: Updates on How to Make Foods and Beverages Sweeter with Sight, Smell, Sound and Touch

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November 2nd, 2016
Re-Defining “Flavor” = Taste + Smell + More

- Taste (5+ primary)
- Smell (aroma)
- Somatosensation: Touch, Pressure and Vibration (mechanoreception) (Prescott, 2015), Temperature (thermoception), Pain (nociception) (Youseff, 2015), and others.
- Sight (“Seeing the flavor”. Acree, 2013)
- Sound is the Forgotten Flavor Sense (Spence 2015. Gastropod, 2015)
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, one brain region. Zuker, 2016). There is integration of gustatory information from different taste cells (Sternini, 2013), that is “sensory processing circuitry” (Bigiani, 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. And a newly found secondary pathway.
- **Umami**: 1 Receptor: T1R1/T1R3. Family: GPCR. 2002.
- **Saltiness**: “Receptor”: ENaC. Family: Na Channel. 2010. And a newly found secondary pathway in Type III cell.
- **“Fat”**: Receptors: CD36, GPR120, FA1. Family: Several GPCR.
- **“Calcium”**: Receptor: CaR. Family: GPCR
- **“Water”**: Receptor: Aquaporins. Family: Channel
- **“Starchy”**: Proposed (Lim, 2016)
Sweet Taste Receptor

A Secondary Sweet Taste Pathway

Only caloric sucrose and maltose, hydrolyzed into simple sugars by sucrase or maltase next to tongue sweetness receptor, triggered a newly found secondary pathway (Margolskee et al, Monell, 2016)
Sweetness Transduction

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). 30% of different sensitivity for sweetness perception in population can be explained by genetic difference (Hwang et al, 2015)
Stack Them, Each at Low Usage Level

The stacking strategy is about building up to the required sweetness intensity and profile while staying below the off flavor threshold for all the plant-based ingredients used (AW, W2O, 2016).

Sugar Equivalence (SE)

1% SE

12% SE+

Sweet, Naturally & Simply

Crossmodal Correspondence

Sweetness Modulators

Non-Caloric Bulk Sweeteners: Erythritol and Allulose

HPS: Stevia, Monk Fruit
Make Things Taste Sweeter, “Naturally”

- Keep it plant-based & found-in-nature
  - High potency sweeteners
    - Stevia extract
    - Monk fruit extract (not in EU yet)
  - Non/low caloric bulk sweeteners
    - Erythritol
    - Allulose (not in EU yet)

- Less is More!
  - Stack them, each at low usage level
  - To achieve maximum sweetness yet with minimal off flavors and lowest cost in use.
The First Perception Problem: Sweetness & Bitterness Intensity-Concentration Curves

Stevia RA sweetness was nearly linear for the first 200ppm but plateaued at around 7-9% SE, while RA bitterness started around 200ppm and increased dramatically in beverages. (Idealized curves. AW, W2O, 2016)
The Second Perception Problem: Time-Intensity Curve

The sweetness modulation strategy is to shorten the onset, increase the peak, and reduce the lingering of plant-based HPS.

(Idealized curves. AW, W2O, 2016)
Clean Label Sugar Reduction Roadmap

How to formulate with a stacking strategy:

1. Always start with plant-based high potency sweeteners.
2. Make it sweeter and more like sugar with plant-based non/low caloric bulk sweeteners. Use bulking agents to compensate for missing functional properties from sugar.
3. Lastly, make it even sweeter with crossmodal correspondence.

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. Crossmodal Correspondence
Crossmodal Correspondence

How brain process information from different senses to form multisensory experiences in our daily lives (Spence, 2013) (Smith, 2014)

- Smell on sweet taste
- Touch on sweet taste
- Sight on sweet taste
- Sound on sweet taste
The Second Modality: Smell

Humans have 400 odor receptor genes (Monell 2015, 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(s) (OR) expressed by olfactory sensory neuron (OSN) in the olfactory epithelium. Each mature OSN expresses only one type of OR (up to 7 OR in young) (Buck et al, 2015) and operates in a “Cooperativity” principle (Buck, Axel and Xing, 2016). Axons of these OSNs project directly to the olfactory bulb (OB) (Cheetham and Belluscio, 2014).

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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 gustation and olfaction (Taylor, 2010) or “binding” (Lewandowsky, 2015). That is, retronasal “sweet” aroma (smell) in the nose increases the sweet perception in the mouth (taste). (Prescott, 2015)
Stack Them, Each at Low Usage Level

The stacking strategy is about building up to the required sweetness intensity and profile while staying below the off flavor threshold for all the plant-based ingredients used (AW, W2O, 2016)

Sugar Equivalence (SE)

17

12% SE+

1% SE

Sweet, Naturally & Simply

Crossmodal Correspondence

Sweetness Modulators

Non-Caloric Bulk Sweeteners: Erythritol and Allulose

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Taste & Smell Crossmodal Association

Retronasal “sweet” smell is how we can make the perception of what’s in the mouth sweeter. All of these sweet taste modulators (in black) are legally labeled as “natural flavor” for those countries honor FEMA GRAS (AW, W2O, 2016)
Smell on Sweet Taste

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

- Example: Sugar distillate and citrus extracts enhanced beverage sweetness, tea essence enhanced sweetness in tea (Suppliers’ literature, 2016)

- Example: Fresh tomato aroma made tomato tasted sweeter (Bartoshuk, 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 on Sweet Taste

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

Example: Retronasal sweet aroma in the nose enhanced sweet taste perception in the mouth in ciders (Symoneaux et al, 2015), same for strawberry odour in 5% sugar solution (Prescott, 2015) even imagined one too (Prescott, 2016)

Example: The more congruent the smell and taste, the more intense was the flavor (Amsellem, 2016)
Smell on Sweet Taste

Some FDA GRAS plant-based high potency and bulk sweeteners are also approved under FEMA GRAS, as “natural flavor” when used at extremely low level as sweetness enhancers (FEMA GRAS 25, 26 and 27 prior to 2015; 28 in 2016)

- Example: Thaumatin (0.5 to 1ppm. FEMA 3732). (<5ppm in beverages in EU, E957)
- Example: Monk fruit extract (< 60ppm in beverages. FEMA 4711)
- Example: Stevia extract (< 30ppm for RA60% FEMA 4771, < 35ppm for RA80% FEMA 4772)
- Example: Erythritol (<1.25% in beverages, FEMA 4819)
“Smell” on Sweet Taste

Receptor-based PAM (Positive Allosteric Modulators) are taste-less compound that binds to the allosteric site next to a bound sweetener on the GPCR, increasing its binding efficacy and affinity thus potency. They are being developed based on taste receptors and high throughput screening.

- Company S: S617 and SR96 (FEMA 4774) for sugar for example. Labeled as “artificial flavor”. (company website, 2016)
- Company C: Reportedly developing PAM that are “natural flavor”. (company website, 2016)
Stack Them, Each at Low Usage Level

The stacking strategy is about building up to the required sweetness intensity and profile while staying below the off flavor threshold for all the plant-based ingredients used (AW, W2O, 2016)

Sugar Equivalence (SE)

- 1% SE
- 23 SE
- 12% SE+

Crossmodal Correspondence
Sweetness Modulators
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Crossmodal Correspondence
How brain process information from different senses to form multisensory experiences in our daily lives (Spence, 2013) (Smith, 2014)

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- Sound on sweet taste
Touch on Sweet Taste

Somatosensation 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)
Sight on Sweet Taste: Shape

- Vision on sweetness: (Shape Symbolism - Sub-consciously setting up sensory expectations in the minds of consumers. Spence, 2013). Use packaging color/shape to enhance taste (Spence et al, 2016)
  - Sweet was round, other tastes were angular. No word on umami (Velasco et al, 2016)
  - Symmetrical and fewer elements in shape = sweeter (Montejo et al, 2015)
  - Shape (food): More rounded shape tended to associate with sweeter stimuli (Spence, 2013) including juices (Spence, 2013) and beets (Smith, 2015)
  - 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)
Sight on Sweet Taste: Color

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

- Color (contextual): Color pairs cross talked with taste more consistently but more slowly (Woods & Spence, 2016)

- Color (contextual): Red room, red fruits, and red round shape objects in a “sweet room” made whisky tasted sweeter (Spence 2013). Red light made red wine sweeter and fruitier (Spence, 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)
Sight on Sweet Taste: Color

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

- Color (emotion): Color influenced taste and smell perception through a link of emotion (Gilbert et al, 2016)

- Color (intrinsic) Lighter color = Sweeter (Spence, 2015)

- Color (cognition): Congruent color effect on sweetness perception was mainly based on cognitive processes, not perceptual processes (Hidaka and Shimoda, 2014).
Sight on Sweet Taste: Shape & Color

- Shape and Color both
  - Latte Art: **Round** shape = Sweeter,
    Angular shape = More bitter (Spence, 2015)
  - **Red**= Sweet, **Green**= Sour,
    White = Salty, Black=Bitter
    (Spence and Youssef, 2015)
Sound on Sweet Taste

- **Sound**: The forgotten flavor sense
  - On airplanes (noises, humidity, pressure, stress), Umami was the only primary taste not muted (Dando and Yang, 2015) or even enhanced (Dando, 2015). Sweet and salty perception were reduced 30% (GFIBP, 2010)
  - Pitch-taste cross talk influenced by pleasantness (Wang et al, 2016)
  - **Mouth-watering words** (Topolinski and Boecker, 2016). P and B are more palatable, K is not. Inward Wandering brand name.
  - **Bouba and Kiki**: Bouba = round = sweeter and fatty = smooth motion, Kiki = angular = bitter and citrusy = sharp motion (Spence, 2015) (Koppensteiner et al, 2016). More to do with sound-emotion than sound-shape (Karthikeyan et al, 2016). In-between shapes could be “primed” (Sidhu & Pexman, 2016)
  - Music and smell cross talk mediated by emotions (Levitan et al, 2015), same for sound-taste (2015)
Sound on Sweet Taste

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) “Sonic Seasoning” (Spence, 2014)

- Twinkling/Higher pitches enhances sweetness in toffee or chocolate, and lower tones emphasize bitterness (Crisinel, 2012) (Spence, 2015). Made red wine sweeter and fruitier (Spence, 2014) and beer sweeter (Spence, 2016) (Carvalho, 2016). Same for red color+ high pitch music (Chambers et al, 2016) More driven by taste quality and less so by intensity (Spence et al, 2016).
- Chocolate gelati: The more one liked the background music, the sweeter the gelati tasted (Kantono et al, 2016)
- “Creamy “ music made chocolate seemed creamier and sweeter (Carvalho et al, 2016)
- Consonant music made juice tasted sweeter (Wang & Spence, 2015)
- Higher frequency sounds pair well with sweet wine (Burzynska, 2013)
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