SWEETNESS AND SWEETENERS

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By

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ABSTRACT

Sweetness is a pleasant sensation that has been sought by mankind throughout history across all cultures. This literature review is a general overview of sweeteners and related topics. It discusses the relationship between human perception of sweetness, the evolution of sugar manufacturing that made sugar, sweet-tasting carbohydrates, widely available to most consumers around the globe, and the recent development and growth of low caloric sweeteners and non-nutritive sweeteners started in the last century. Pure sugars such as sucrose, fructose and maltose are listed and introduced in the review, and they are compared with common sugars in the food industry such as corn syrup, and with high-intensity synthetic sweeteners such as saccharin and sucralose. This review also examines the consequences of this dramatic upsurge in sugar consumption, including significant increase in number of patients suffering from diseases related to carbohydrate intake. The final part of the review aims to provide insights on the future of “sweetness” in food and beverage industries by analyzing the consumer trend, and the effects of sweeteners on human body.

BIOGRAPHICAL SKETCH

Hao Wang obtained his Bachelor degree of Economics in Shenzhen University in 2010, Master degree of Business Administration in Rensselaer Polytechnic Institute in 2012, and Master of Science in Entrepreneurship and Innovation in University of Southern California in 2017. He continued learning in food science as an MPS student in Professor Rui Hai Liu's lab with his 7 years working experiences in food industry. His research is concentrated on sugar and sweeteners.

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History of Sugar

When mentioning the word sweet, most modern consumers would relate this pleasurable taste to sugar. However, this desirable sensation was associated with numerous compounds throughout human history during different time periods. Pre-historic humans were likely to link sweet taste with honey. This nutrient-rich compound that reaches high level of sweetness can be found in the wild on African continent, and it was gathered and consumed by ancient humans and primates alike. Some evidences show that indigenous Polynesians were the first people to domesticate wild sugarcane plant and consume its juice by chewing (Deerr, 1949, p. 15). When Persian invaders reached India in 5th century BC they discovered this "reed that gives honey without bees." (Gopel, 1964, p.58). The new rulers kept the knowledge of this plant along with the extract of its juice as secrets and sold the syrup to the wealthiest people in the then known-world for enormously high profit. Starting from this point, a small pocket of people started associating "sweet" with sugarcane syrup. Around 350AD, Indians discovered the method to extract and crystalize sugar from sugarcane plant (Gopel, 1964, p.68). To profit from this new industry, massive labor force including elephants were mobilized to increase its production. Indian sailors and Buddhist missionaries brought the knowledge of sugarcane cultivation and sugar crystallization to China. This delicacy caught enough attention from its emperor, that his royal court sent out at least two missions to India in the hope of improving sugar-refining process in China. In the west, the Arab conquest in the 7th century shattered the monopoly of this knowledge from Asia. These nomadic people, having an expansive social and economic network across three different continents, soon realized the value of this product, and began expanding it production in North Africa and Spain (Deerr, 1949, p. 63). The sugar industry was so profitable, that Arab businessmen employed artificial irrigation to grow sugarcane in North Africa and Spain, which is different from its native tropical regions. During the first crusade in 11^{th} century, crusaders brought home sugar known and enamoured by Europeans as the “sweet salt”. Around a hundred years later, Venetians began cultivating sugarcane and producing sugar in the Christendom, and traded it with the rest of Europe. The discovery of the New World incentivized European entrepreneurs to expand sugarcane plantations in the new land. On one hand, the high profitability of this industry encouraged the invention of new tools, and correspondingly, the technology to manufacturing them. These technological improvements provided preconditions for industrial revolutions in the following centuries. On the other hand, the labor intensity of the industry transformed the relatively small slave-trade carried on from medieval era. Millions of new slaves were kidnapped from Africa and forced to work on sugarcane plantations in the Americas, while products such as sugar and rum were shipped to Europe, forming the notorious Triangular Trading System (Klein, 2014). With the expansion of its production and more efficient manufacturing technologies bestowed by the industrial revolution, sugar price steadily declined while became more available to consumers; the word sweet became closely associated with sugar (Deerr, 1949, p. 103).

Sweet and Sweeteners

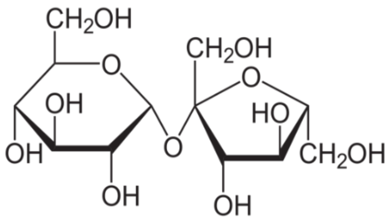
The reason behind such intensive pursuit for sweetness in human history may be found in human biology as perceiving sweetness is innate among human. Newborns and premature human infants show positive responses to sweet molecules at their first presentation. Researchers believe that sweet stimuli can trigger the release of endogenous opioids, directing infants to seek for milk, as it contains sweet tasting lactose. It is also evident that sweet treats can calm young children when suffering from minor pain (Eikemo, et al., 2016). However, this ability is not universal among all animals, neither is sweet a singular sensation. Species in the order Carnivora that do not consume plants cannot perceive sweet taste due to the pseudogenization of a component of the primary sweet taste receptor. (Beauchamp, 2016) Obligate carnivores such as cats are indifferent to sweet taste as they consume other animals. It is believed that many primates, including human, perceive sweet taste to examine the level of nutrition with in a plant as food. (Jiang, et al., 2012) However, some researchers believe that sugars are the least essential of all nutrients. (Brown, 2014) Fruits that has the most intensive sweet taste are relatively low in energy, and sweetness is not a good indicator of other nutrients such as fat and protein. Sweet taste can also be triggered by many distinctive sources. Calorie rich honey and sugar, including sucrose, fructose, are among the earliest known sweet spices. However, humans are no strangers to low calorie sweeteners. Ancient Asian communities brew monk fruit in hot water to produce a cooling sweet tea in the summer, and more recent discovery such as stevia leaf extract adds more to the list (Dharmananda, 2004). In addition to natural sweeteners, human also experiment in laboratories to find synthetic ones. The first movement of anti-sugar can be traced back to 17th century as medical pioneers during the time indicated that "Sugar-plummes heateth the blood. . . Rotteth the teeth. . . And withall, causeth many time a loathsome stinking-breath." (NY Times, 1987). There is always a demand for cheaper, healthier alternative for sugar. The earliest among them is saccharin, found by accident more than a hundred years ago in John Hopkins university. Despite its bitter after taste, this substance is 300 to 400 times sweeter than sucrose; its capable of mechanical mass production and requires little land and labor, let alone irrigation, sunlight and the suitable climate (Spiller, 2011). The second addition to the category is cyclamate, introduced by Abbot Laboratories for diabetics. These early substitutes had major setbacks when researchers discovered their negative health effects. Nevertheless, more recent developments such as aspartame, sucralose, and neotame are healthier than their predecessors and are more effective in mimicking the taste of sucrose. They may shed light on the future of food and beverage industries which will cater to more health and taste conscious consumers.

There are many approaches to categorize the current sugars and other sweeteners. The basic factors in determining the application of sweeteners lie on three aspects: natural or artificial, caloric or non-caloric, high intensity or low intensity. Below chart includes some of the major sweeteners:

	Natural	**Artificial**
Caloric	Sugars (Sucrose, Glucose, Dextrose…), sugar alcohols (Sorbitol, Xylitol, Mannitol…)	Modified sugars (High-fructose corn syrup, Caramel…)
Non-caloric	Luo Han Guo, Stevia…	Aspartame, Sucralose, Saccharin, Neotame, Acesulfame K, Cyclamate…
High intensity	Stevia	Aspartame, Sucralose, Saccharin, Neotame, Acesulfame K, Cyclamate…
Low intensity	Sugars and sugar alcohols (Sucrose, Glucose, Dextrose…) (Sorbitol, Xylitol, Mannitol…)	Modified sugars (High-fructose corn syrup, Caramel…)

I. Sugars

1. Sucrose:



Chemical Formula: $C_{12}H_{22}O_{11}$

1.1 Properties:

Sucrose is the main product of photosynthesis, and it is widely found in plants, especially in sugar beet, sugar cane and all types of fruit. Sugar with sucrose as its main component are categorized into: rock sugar, white sugar and red sugar (also called brown sugar or raw sugar) in accordance with the level of concentration of sucrose, in descending order. In nature, sucrose is most abundantly found in sugar beet and sugarcane. “Table sugar” most commonly refers to white sugar with chemical energy of 17 kJ/g (Hough, 1995, p.12).

Sucrose is a colorless crystal that consists of enantiomer. The molecular formula of sucrose is C12H22O11. Sucrose is easily hydrolyzed by acid; the resulting products has equivalent amounts of D-glucose and D-fructose. The caramel formed by fermentation can be used as a coloring agent for food and condiments such as soy sauce (Hough, 1995, p.186).

Sucrose is highly soluble in water, aniline, nitrogen benzene, ethyl acetate, and in mixtures of alcohol and water. It is insoluble in gasoline, petroleum, anhydrous alcohol, CHCl3, CCl4. Its solubility in water is as follows: 2.1 g of sucrose per gram of water, solubility 210 g (25 ° C). In other words, sucrose is a highly soluble sugar.

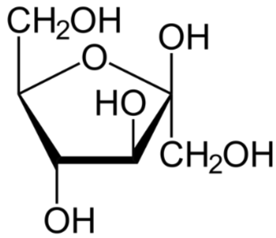
1.2 The role of sucrose in the food industry:

Sucrose is a nutritious sweetener widely used in the food industry. It has become an important additive in foods not only because of characteristics that synthetic sweeteners do not possess, which facilitates food processing and improves their quality. For instance, the sweet taste of sucrose is relatively pure and stable, and it dissolves easily just as it is conducive to food coloring; it also crystallizes rapidly from saturated solutions. These properties make sucrose an ideal ingredient in the production of confections (Pennington & Baker, 1990, p. 62). In addition to being used as a sweetener, sucrose is used as a refreshing agent, a crystal modifier, and a leavening agent in foods such as ice cream (Pennington & Baker, 1990, p. 65). Sucrose can also be cooked at high temperatures, giving the cooked food and baked goods a desirable brown sheen. Sucrose has an osmotic effect, which can inhibit the growth of harmful microorganisms. It is thus used to preserve various jams, jellies and candied fruits to prolong their shelf life (Pennington & Baker, 1990, p. 82).

While sucrose is highly soluble in water, it produces different viscosities for solutions at different concentration. This provides manufactures means to bring desirable characteristics for their beverages, canned foods, etc., and helps them to maintain the stability of their flavors. Sucrose can be used as a nutrient in yeast, which provides energy for various fermentation processes; this a property that most chemically synthesized sweeteners lack (Pennington & Baker, 1990, p. 117).

Sucrose also has water absorption and water retention properties, which can be used to soften various foods (especially pasta), which is used to keep retail food products in a merchandisable condition. Lastly, sucrose swells and gels starch granules, which is used to facilitate the preparation of various breads and pastas (Pennington & Baker, 1990, p. 134).

2. Crystalline Fructose



（β-D-Fructofuranose）

Chemical Formula: $C_6H_{12}O_6$

2.1 Properties

Crystalline fructose is a highly hygroscopic, usually in the forms of odorless crystal or crystalline powder. Its sweetness is 1.6 times that of sucrose, crystalline fructose is a monosaccharide, the most chemically active of all sugars, and it is naturally occurring in honey and Jerusalem artichoke and chicory (Rippe, 2016, p.13).

Fructose has a fruity aroma, low calorific value and metabolizes in the body faster than glucose, making it relatively easy to be absorbed by the body, and it does not depend on insulin for the process (Rippe, 2016, p.15). Fructose has little effect on blood sugar and, thus, is a suitable source of energy for patients who has issues metabolizing glucose and liver dysfunction (Rippe, 2016, p.113). In the human body, it can promote the growth and reproduction of beneficial bacteria such as Bifidobacterium, inhibit the growth of harmful bacteria, improve human gastrointestinal function and metabolism, reduce blood lipids, and does not cause dental cavities. It is an ideal sweetener for diabetics, patients suffering from obesity and as an ingredient in children's food (Rippe, 2016, p.114).

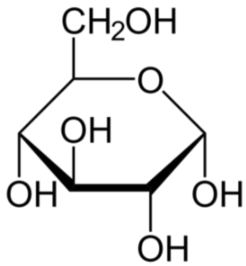
Temperature, pH and concentration levels will all affect the sweetness of fructose, with temperature as the most significant factor. The taste buds in human tongues detect fructose more quickly than glucose and sucrose, although its sweetness dissipates quicker as well (Rippe, 2016, p.87). The rapid vanishing of the sweetness of fructose has a refreshing effect with a sweet aftertaste, which does not obscure other flavors and is, thus, conducive to maintaining the original flavor of the food.

2.2 Application:

The deliquescent property of fructose is quite high, that is, its water absorbance is strong and, thus it is difficult to form fructose crystals from an aqueous solution. Today, crystalline fructose is mostly made from high fructose corn syrup mixed with alcohol. This is because fructose is far more difficult to dissolve in alcohol. The fructose crystals are often used to coat foods as icing, and the crystals absorb moisture from both the food and the air and, as a result, dissolves quickly into a thin layer of viscous syrup.

The time it takes for people to taste the flavor of the different ingredients in foods differs. The sequence and overlap of the flavor peaks of different ingredients will greatly affect the expression and experience of the totality of flavor. The peak of the sweetness of fructose occurs before the peak of the taste of other ingredients. In other words, the flavors of other ingredients are unaffected by fructose and also enhanced by its preceding sweetness. Since fructose diffuses faster in water than other sweeteners, the lower viscosity fructose solutions also contribute to the enhancement of other flavors. A sweetener's reactivity with water directly affects the chemical stability, enzyme stability and tissue structure of the food; and since fructose is the most chemically stable in water among all sugars and sugar alcohols, it is one of the most effective sweeteners for reducing water reactivity in foods.

3. Glucose



(α-D-glucopyranose)

Chemical Formula: $C_6H_{12}O_6$

3.1 Properties

Glucose is also known as corn sugar and jade sugar; it is the most widely found and most important naturally occurring monosaccharide. It is a polyhydroxy aldehyde, a colorless crystal or white crystalline or granular powder; it is odorless, sweet, hygroscopic, soluble in water, although it is not as sweet as sucrose (as most people cannot taste its sweetness). Glucose is also slightly soluble in ethanol, but insoluble in ether. The natural glucose aqueous solution is optically rotated to the right, so it is classified under "dextrose" (Hull, 2010, p.13).

3.2 Method of production:

The sugary aqueous solution obtained by partially hydrolyzing corn starch with food grade acid and/or enzyme is purified and concentrated. The amount of D-glucose contained may vary greatly due to the degree of hydrolysis. Made from corn starch, it is called "corn syrup" (Hull, 2010, p.36).

3.3 Application:

In the food industry, glucose can be processed by isomerase to produce fructose, especially fructose syrup containing 42% fructose. Due to the equivalence of its sweetness to sucrose has become an important product for the sugar production industry (Hull, 2010, p.80).

4. Fructose Syrup

4.1 Properties

Fructose syrup's composition consists mainly of fructose and glucose. It is a colorless, viscous liquid with good fluidity and it is odorless at room temperature. Fructose syrup is mainly composed of glucose sugar and fructose. Fructose syrup is divided into three industrial standards, according to its fructose content: fructose syrup (F42 type) contains 42% fructose; fructose syrup (F55 type) contains 55% fructose, and fructose syrup (F90 type) contains 90% fructose. The sweetness of fructose syrup is positively correlated with fructose content (Williams, 1992, p.92).

4.2 Method of production:

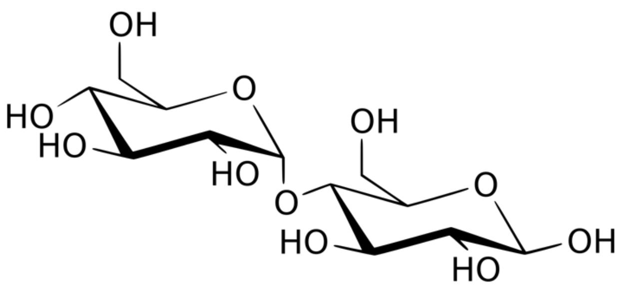
In the food industry, glucose can be processed by isomerase to produce fructose, especially fructose syrup containing 42% fructose. Due to the equivalence of Its sweetness to sucrose, glucose has become an important product in the sugar production industry (Williams, 1992, p.95).

4.3 Application:

Like sucrose, it is widely used in the food and beverage industry. This is particularly true in the beverage industry, as it tastes is more favored among consumers than sucrose. Additionally, the increase in the price of sucrose has made fructose syrup an increasingly popular sweetener in food and beverages. The sweetness of fructose syrup is close to that of sucrose in the same concentration. The taste of fructose syrup is similar to that of natural fruit juice. The presence of fructose creates a fragrant and refreshing feeling. Also, fructose syrup maintains its sweetness at 40 ° C or lower, and the sweetness increases as the temperature decreases.

Fructose syrup can be used to completely to replaces sucrose, as its sweetness is about 90% of the same amount of sucrose (Williams, 1992, p.108). When used to partially replace sucrose, the overall sweetness is still the same as that of the same concentration of sucrose due to the synergistic effect of fructose, glucose and sucrose sweetness. The replacement of sucrose with fructose syrup in foods, beverages, etc. is not only cost effective and technically feasible, but also advantageous due to the fragrance and refreshing properties of fructose syrup.

5, Maltose



(β-Maltose)

Chemical Formula: $C_{12}H_{22}O_{11}$

5.1 Traits:

Maltose is type of carbohydrate, which is prepared through the reaction of malt containing amylase on starch. Maltose can be used as a nutrient, it is also used in the preparation of culture media. Maltose is a colorless crystal and, while sweet, its sweetness is about one-third that of sucrose. Maltose is water soluble, slightly soluble in ethanol and nearly insoluble in ether. Its ability to prevent oxidation is stronger than other sugars, and it has more effective antibacterial ability than sucrose as sucrose solution requires a concentration of 60% or more to achieve the effect equivalent to that of 40% maltose solution. Maltose does not brown easily.

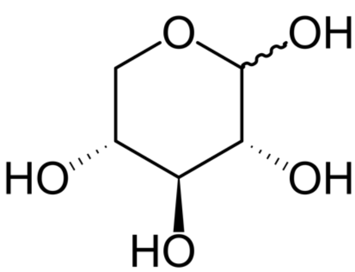
5.2 Method of Production:

Maltose is made by using starch as raw material, followed by liquefaction by α-amylase and, then, saccharification by β-amylase, which will yield a product with over 70% purity. Generally, barley malt is used in starch to obtain a mixture of dextrin and maltose (with maltose making up about one-third of the solution).

5.3 Application:

Maltose can be used as sweeteners or hygroscopic agents, mostly, in foods with a low-sweetness level, and while the sweetness in the flavor is reduced, the concentration of sugar does not change, which continues to inhibit the proliferation of microorganisms. Its hygroscopic properties can prevent the dissolution of confections and other foods, as it improves its chemical structure, and helps keep its texture soft for prolonged periods of time. Maltose syrup, a yellow to brown viscous transparent liquid, with a sweet taste and produced by heating and gelatinizing starchy raw materials, adding dry malt, then controlled using the derivative amylase, subject to pressure filtration, sulfur dioxide bleaching and vacuum concentration to produce the final product. The syrup contains 40%~65% maltose, 13%~23% dextrin, and 75%~80% solid content.

6. D-xylose



(D-Xylopuranose)

Chemical Formula: $C_5H_{10}O_5$

6.1 Traits:

D-xylose is a colorless or white crystal or crystalline powder, with a peculiar smell and tastes refreshingly sweetness. Its sweetness is 40% that of sucrose, it is soluble in water and hot ethanol, but insoluble in cold ethanol and ether. It cannot be digested or utilized by the human body.

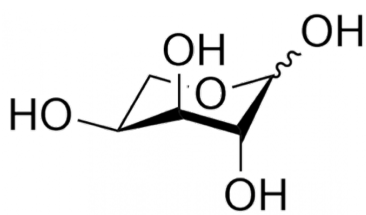
6.2 Production Method:

D-xylose is obtained by acid hydrolysis of the cob of corn, and it can also be hydrolyzed by combining wood and acid in order to hydrolyze the xylan in wood into D-xylose, which is then concentrated and refined using yeast and the process of fermentation to remove the glucose.

6.3 Application:

D-xylose is a non-caloric sweetener, which can also be used to produce fat oxidation inhibitors; and it is used with other ingredients to give pork and other meats a distinctive flavor through the Maillard reaction.

7. L-arabinose



(L-arabinopyranose)

Chemical Formula: $C_5H_{10}O_5$

7.1 traits:

L-arabinose is a new type of low-calorie sweetener, it is widely found in the skins of fruits and whole grains. L-arabinose can inhibit the activity of sucrose in the human intestinal tract, thereby inhibiting the absorption of sucrose. Additionally, L-arabinose also inhibits body fat accumulation and can therefore be used to prevent diseases such as obesity, high blood pressure, and high blood fat.

It has been reported that the addition of 3.5% L-arabinose inhibits the absorption of 60-70% sucrose and also prevents blood sugar level from increasing by about 50%. The Ministry of Health and Welfare in Japan lists L-arabinose as a special health food additive for regulating blood sugar; the American Medical Association labeled L-arabinose as an "anti-obesity nutritional supplement or over-the-counter" drug.

L-arabinose is widely found in fruits. In the case of coarse grain husks, humans have been eating it for thousands of years, but it was only in recent years that scientific research discovered that this substance has the ability to prevent high blood pressure, high blood sugar, high blood fat, diabetes and obesity.

7.2 Application:

L-arabinose is used in food and health products for diabetics, patients suffering from obesity, health supplement, as well as a sucrose-based additive. L-arabinose is also an additive or excipient in prescription and over-the-counter drugs used for weight loss and the control of blood sugar levels. L-arabinose is also an ideal intermediary for the synthesis of flavors and fragrances, drug and the organic synthesis and various chemical reagents.

8. Corn Syrup

8.1 traits:

Corn syrup is made using high-quality corn starch, through the hydrolysis of a variety of enzymes to produce maltose-based syrup. The end product is a colorless, transparent and viscous liquid, and mild and pure in taste. It has low sweetness, a malt flavor and has many advantages such as high cooking temperature, low freezing point and anti-crystallization properties. It is often used in jams and jellies to prevent the crystal precipitation of sugar. High malt has good expandability, so it is also widely used in the production of breads, cakes, and beers, as well as in candy, beverages, frozen foods and condiments. (Alexander, 1998, p. 60)

8.2 Application:

Fructose corn syrup can also be used as a sweetener for carbonated beverages in part or in whole. In fact, it is often used as the sole sweetener for base syrups and as a flavor concentrate for carbonated beverages. For non-carbonated beverages, high fructose corn syrup can also be used with glucose or high DE (dextrose equivalent) value corn syrup. In soy sauce, high fructose corn syrup can be used and the DE value of corn syrup can be increased. Light salad dressings can also be made with high fructose corn syrup alone or in combination with other syrups. High fructose corn syrup can be used alone or in conjunction with other corn syrups in yeast fermented baked goods. High fructose corn syrup can enhance fermentation and residual sweetness and form a brown color in baked goods. Common baked goods that use high fructose corn syrup include pastries, pitted-fruit cakes, and cookies.

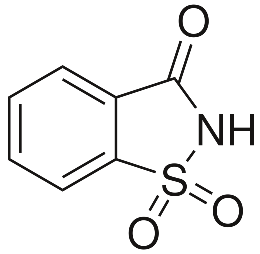
II. High-Intensity Sweeteners

Sweeteners can be classified into synthetic sweeteners and natural sweeteners according to the source; and can be further classified into high-intensity sweeteners and low-intensity sweeteners based on the degree of sweetness.

Generally, the sweetness of high-intensity sweeteners is at least tens of times higher than that of sucrose, which can better replace sucrose and reduce the cost. They are normally non-nutritive sweeteners and below is a list of them which are common in modern food and beverage industries.

1. Saccharin:

Saccharin includes homologous saccharin, sodium saccharin, ammonium saccharin, potassium saccharin, etc. The most commonly used is sodium saccharin.



1.1 Chemical Formula: $C_3H_4NaO_3NS.2H_2O$

1.2 Properties

A water soluble odorless white crystals or crystalline powder. It is 500 times sweeter than sucrose with metallic aftertaste; detectable bitterness when concentration is greater than 0.02% (10% sucrose solution sweetness). Its sweetness vanishes and transforms into bitterness when heated under acidic conditions (Nabors, 2016, p152). It is usually used together with cyclamate in countries that do not have a ban on cyclamate (Nabors, 2016 p.4).

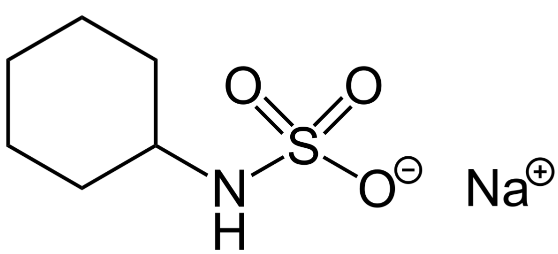
1.3 Application:

Widely used as food additives in beverages, preserved fruits, bread and pastries, cookies, cocktail, etc. It is also used as feed additives for animals that also have perception for sweetness. In the health and beauty industry, it is added in toothpaste, mouthwash, eye drops.

1.4 Disadvantage

Poor flavor profile with bitter aftertaste, limited usage in baking, frying, and acidic food processing for its nature of diminishing sweetness and release ammonia odor under heat or acidity. It is susceptible to acid hydrolysis; any acidic ingredient should generally enter the product after sodium saccharin (Nabors, 2016, p155).

2. Cyclamate (sodium cyclohexyl sulfamate)



2.1 Chemcial Formula: $C_6H_{11}NHSO_3Na$

2.2 Properties

White Odorless needle or flaky crystal, or powder with sweet taste. It has neutral pH in 10% solution (pH=6.5); relatively stable to light and heat; slight bitterness emerges when heated; stable in alkaline conditions; slightly decomposable in acidity; soluble in water（≥10 g/100 mL，20°C）; almost insoluble in organic solutions such ethanol, ether, benzene, and chloroform; 30 to 50 times sweeter than sucroses; a noticeable rubber-like chemical odor appears at high concentration (Hunt, Bopp & Price, 2016, p.93). Number of research shows that cyclamate causes harm to the human liver and nervous system especially for those with weaker metabolism and detoxifying ability such as the elderly, pregnant women and children (Nabors, 2016 p.5). Thus the additive is banned in several countries including the US. Noticeable bitterness when the concentration is greater than 0.4%; soluble in water with high nitrite and sulfite in presence, producing a petroleum or rubbery odor.

2.3 Application:

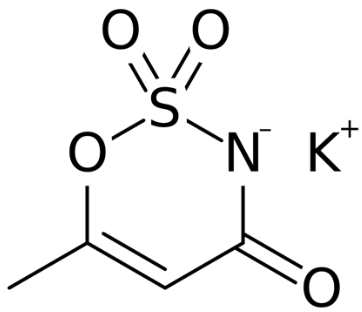
Food additives: Beverages, roasted goods, preserved fruits, bread and pastries, cookies, cocktail, home seasoning, pickles etc.

Other: cosmetics, syrup, sugar coating, sweet ingots, toothpaste, mouthwash, lip bum, etc.

2.4 Advantage

Cyclamate reveals intensely expressive sweetness in certain products; usually used together with saccharin sodium to cover the bitterness. Its synergetic effect with other sweeteners is significant. The sweetness level can reach 80 times or more when used with sucrose; and 100 times or more when used with 0.3% organic acid such as citric acid (Hunt, Bopp & Price, 2016, p.93).

3. Acesulfame Potassium



3.1 Chemical Formula: C_4H_4KNO4S

3.2 Properties

White crystalline powder; soluble in water; slightly soluble in ethanol (30 g / 100mL, 20 ° C); 150 to 200 times of sweeter than sucrose; similar taste as saccharin with metallically bitter aftertaste. The sweetness expresses and vanishes rapidly; does not absorb moisture in the air; resistant to heat up to 225 Celsius degree. Its sweetness is not obvious under acidic conditions (Klug & Lipinski, 2016, p 14).

3.3 Application:

Food additives: Beverages, roasted goods, preserved fruits, bakery, seasoning, jelly, candy, gum, pickles etc.

Other: Cosmetics, oral hygiene, mouthwash, toothpaste, lip bum, medicine, syrup, sugar coating, etc.

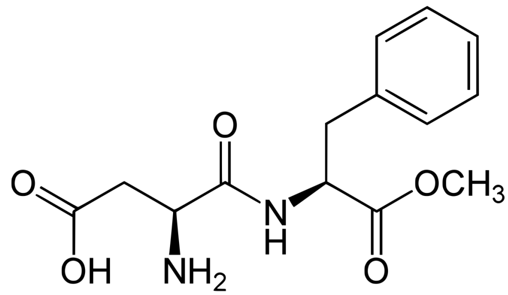
3.4 Advantage:

The synergetic compounding effect with other sweeteners is significant.

Disadvantage:

Poor flavor profile with metallic, bitter aftertaste. Limited usage under heated and acidic conditions, under which the sweetness disappears (Klug & Lipinski, 2016, p 14).

4. Aspartame



4.1 Chemical Formula: $C_{14}H_{18}N_2O_5$

4.2 Properties

White crystalline powder; 180 to 200 times sweeter than sucrose; stable between pH3 to pH5. It is not resistant to heat and is easily decomposed in conditions over 85 degrees Celsius. It has sucrose-like sweetness, without metallic bitterness. The sweetness last comparably longer than sucrose, which some consumers find unacceptable (Abegaz et al., 2016, p57).

4.3 Application

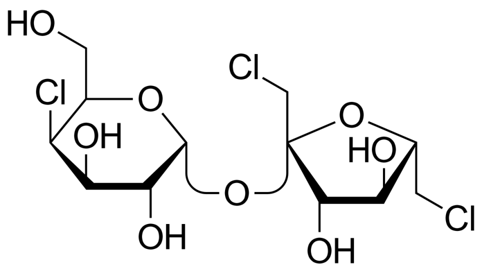
All food except canned food, due to the heating process in manufacturing; added according to production needs

Advantage:

The sucrose-like sweetness taste more natural compared with most synthetic sweeteners. Good compounding effect with other sweeteners (Abegaz et al., 2016, p. 59).

Disadvantage: intolerable to heat and alkaline and neutral conditions. It has poor solubility and forms white precipitate dots at high concentration. When used in some powdered beverages, the amino group of aspartame would react with the aldehyde group on certain aromatic compounds, resulting in the simultaneous loss of sweetness and aroma. The stability of aspartame in water is mainly determined by the pH levels. It is most stable at room temperature ay pH level of 4.3, under which the half-life period can reach 300 days, while at pH 7, its half-life can only last for a few days (Abegaz et al., 2016, p.60-65).

5. Sucralose



5.1 Chemical Formula: $C_{12}H_{19}Cl_3O_8$

5.2 Properties

White crystalline powder; odorless; non-hygroscopic; 600 times sweeter than sucrose; the most similar to sucrose among all the high-intensity sweeteners; highly stable; tolerable to heat, acid and alkali; Rarely react with other substances in food processing; soluble in water and ethanol (Lee-Grotz et al, 2016, p.182-195).

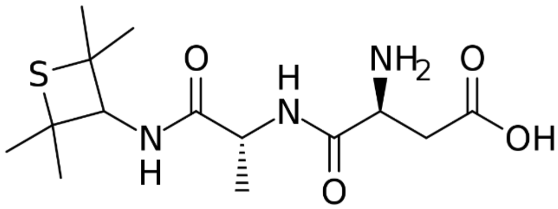
5.3 Application

Flavored milk, frozen drinks, candied fruit preserves, pickles, jams, fermented bean curd, candies, canned porridge, microwave popcorn, baked goods, condiments, beverages, cocktails, jelly, etc.

5.4 Advantage

The purest sweetness without bitter, metallic, and other odors among other high intensity synthetic sweeteners. The sweetness profile is generally consistent with sucrose. (Lee-Grotz et al, 2016, p.185-190) Its industry performance is among the most stable. It application performances such as tolerance to heat, acid, and alkali, as well as shell life, are superior to other sweeteners (Lee-Grotz et al, 2016, p.182-195).

6. Alitame



6.1 Chemical Formula: $C_{14}H_{25}N_3O_4S$

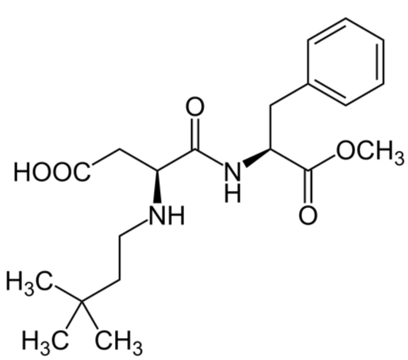
6.2 Properties

A white crystalline powder with slight odor and soluble in water and ethanol. Its sweetness is more than 2000 times that of sucrose. It is stable under acid conditions and heat. When in aqueous solution, it has a pH of 5-8 at room temperature. Its half-life is 5 years at pH 5.6, at 5% aqueous solution. It has no metallic, alkaline, or astringent taste, thus closely resembles sucrose, with long- lasting sweetness. It is also considered safe when compared with early synthetic sweeteners (Auerbach, Locke & Hendik, 2016, p.48-56).

6.3 Disadvantage

Some of the beverages with Alitame are reported to have a slightly sulphurous odor, possibly due to the sulfuric atom in the molecular structure. Some incompatibility will occur after long-term storage. Alitose cannot be compatible with redox substances and strong acids and alkalis (Auerbach, Locke & Hendik, 2016, p51).

7. Neotame (N-[N-(3,3-dimethylbutyl)-L-α-aspartyl]-L-phenylalanine-1-methyl ester)



7.1 Chemical Formula:$C_{20}H_{30}N_2O_5$

7.2 Properties

White crystalline powder, containing approximately 4.5% of water crystallization; solubility in water at room temperature (25 ° C) is 12.6 g / liter; pure and balanced sweetness, very close to aspartame; no bitter and metallic odors that are commonly found in other sweeteners; sweetness of neotame is 8000-10000 times that of sucrose (Mayhew et al., 2016, p 133 -150).

7.4 Application

Under acidic conditions, neotame has approximately the same stability as aspartame; in the neutral pH range or instantaneous heated conditions, neotame is much more stable than aspartame;

Under the normal storage conditions, dry powder form has excellent stability, while solution form is more vulnerable to temperature, pH, and time. The half-life period of the Neotame solution at room temperature (25 ° C) varies across different pH levels: 78 days at pH 3.0; 156 days at pH 4.0; 208 days at pH 4.5; 150 days at pH 5.0; 112 days at pH 5.5 (Mayhew et al., 2016, p 133 -150).

8. Steviol Glycosides

8.1 Properties

Steviol Glycosides, or more commonly known as simply stevia, are a group of chemical compounds refined from stevia plant. It is a natural sweetener that usually has white to slightly yellow appearance in crystalline powder from. It is 200-300 times sweeter than sucrose, and with a slightly cool mouth-feel. At high concentration it produces a bitter, liquorice and grass-like after taste. It is resistant to heat and light, acidity and alkalinity, and stable in pH range between 3 to 10. It is easy to store as it is slightly moisture absorbent. It also has good compatibility with sugar, maintaining its molecular integrity when mixed and stored in sugar-containing solutions

(Carakostas et al., 2016, p. 160-168). Coca-Cola Life, a reduced calorie soft drink exploits this property of stevia.

8.2 Application:

It is used in various food products like other synthetic sweeteners. Its heat-resistant property also enables it to be often used in hot beverages and foods.

8.3 Advantages:

Although stevia is not strictly zero-calorie, its metabolites in human system provides significantly less energy than sugars, and hence it is considered non-nutritive sweetener in many markets (Carakostas et al., 2016, p. 160-168). Its inherent liquorice and grass like aftertaste is undistinguishable when used in plant based beverage such as herbal tea. It is also extract naturally from plants; this gives it stevia sweetened products an advantage when presented to customers who have preference for natural food.

The Trend and Future Development of Sugar and Sweeteners

The consumption of sugar and sugar-sweetened beverages (SSB) has dramatically increased over the last five decades. Sugar-sweetened beverages include fruit drinks, soda, sport and energy drinks as well as liquids sweetened by various forms of sugar. Sweetened beverages have been found to be the primary sources of added sugars in diets. Recent statistics from the Centers for Disease Control and Prevention show that added sugar intake contributed to 13% of total calories for adults in the United States during 2005-2010 period, which was higher than the recommended level. This trend has led to an overall reduction in health and diet quality.

There is a dramatic increase in levels of obesity and overweight with global estimates showing that from 1980 to 2013, obesity and overweight rose by more than 27 % among adults and 47 % among children, which resulted to an increased number of obese and overweight individuals from 857 million in 1980 to 2.1 billion in 2013 (Nguyen et al., 2013). In 2014, 39 % of the world's adult population were overweight while 13 % were obese. Obesity has positively been associated with a higher intake of sugar and sugar-sweetened beverages. World Health Organization (2017a) has concluded that being overweight and obese is a greater cause of death than being underweight (Ludwig, Peterson, & Gortmaker, 2001; Grimes, Riddell, Campbell, & Nowson, 2013).

Globally, the public is consuming an excessive amount of sugar, which is 13 % of the total food energy intake (Bates et al., 2014). Research shows that decreased food group and nutrient intake correlates with an increased added sugar intake consumption (Kranz, Smiciklas-Wright, Siega-Riz, & Mitchell, 2005). This leads to increased calorific intake in satisfying the nutrient requirements of the body, causing deleterious and disastrous effects on the body.

Research shows that increased intake of sugar and sugar-sweetened beverages is associated with higher blood pressure, which generally leads to hypertension (Sayon-Orea et al., 2015; Brownell et al., 2009; A. H. Malik, Akram, Shetty, Malik, & Njike, 2014). Increased intake of sugar has also been found to correlate with increased risk of coronary heart (Huang, Huang, Tian, Yang, & Gu, 2014; Brownell et al., 2009) and cancer (Colli & Colli, 2006; Bristol, Emmett, Heaton, & Williamson, 1985; Slattery et al., 1997).

More studies show that increased sugar intake can be addictive and can change brain neurochemistry (Spangler et al., 2004; Nantha, 2014; Lenoir, Serre; Avena, Long, & Hoebel, 2005). To put this in context, Avena and colleagues (2005, 2008) conducted an experiment on rats and found that when rats had access to sugar, the rats largely became dependent on the substance. Other studies revealed that rats preferred intense sweetness over cocaine even if they were already addicted to cocaine (Lenoir et al., 2007). This was attributed to the fact that foods with high quantities of sugar affect the dopamine, serotonergic and opioid receptors of the brain, changing the brain's neurochemistry in similar ways as addictive drugs do (Fortuna, 2010).

Exposure to foods dense with a lot of sugar leads to the same effects as those seen in drug abuse. Such behaviors include bingeing, craving and withdrawal (Colantuoni et al., 2002; Avena et al., 2005). The number of dopamine receptors harbored in the brain tends to increase by constant bingeing of sugar, as it causes excessive dopamine to be released in the brain, same with opioid stimulation (Spangler et al., 2004; Hoebel, Avena, Bocarsly, & Rada, 2009). Sugar and sugar sweetener consumption therefore has negative effects on the physical and mental health of humans, and has also been linked to deteriorating psychological issues such as depression, distress, stress and suicidal thoughts (Westover & Marangell, 2002; Lien et al., 2006). The World Health Organization (2017a) noted that psychological issues lead to threatening health conditions, which tend to lead to human suffering. The health body notes that depression affects well over 300 million people worldwide, most of whom are at the risk of committing suicide and may also lead to serious anxiety disorders (WHO, 2017b).

As a result of health concerns and threats brought forth by excessive sugar consumption, more people are avoiding sugar and looking for alternative sweeteners. In a research by Nielsen, more Americans say they are cutting back on sugar as their collective awareness rises about the prevalence and potential health impact of the ingredient. The report notes that 57 % of consumers report that low sugar is important in deciding what to buy for their shopping, which is an increase from 55 % in the previous year.

Rising concerns regarding sugar are stemming from the popularity of many available diets that consumers are following, to which 13 % say they follow a specific low sugar diet while 5 % say they follow a diabetes diet. This increase has been attributed to the increase in awareness about sugar content and taxing of sugar-sweetened products. Increasing rates of diabetes could also be playing a role in how consumers make decisions (Nielsen, 2018). The consumption of sugar is therefore declining and will continue to do so due to the health risks outlined above.

Consumers are also checking labels and turning towards sugar-free products. While avoiding sugar, consumers are turning towards natural sweeteners. Beverages and food that have synthetic sweeteners have reduced by 2% with sucrose and fructose going down by 3%, leading to 54 % of consumers avoiding synthetic sweeteners. The alternatives are natural sweeteners, and products with stevia are growing by 12 %. Products with honey and monk fruit are also experiencing strong growth (Nielsen, 2018). Further, consumption of stevia has been linked to health benefits. Stevia has been found to lower blood pressure in people with hypertension by 6-14 %. Stevia has also been found to lower blood sugar levels in people with diabetes. Further, stevia can improve insulin sensitivity, reduce oxidized cholesterol and reduce buildup of plaque in arteries. On the other hand, synthetic sweeteners like aspartame have been linked to side effects such as migraines, shrunken thymus glands, headaches and mood disorders, to which they have come under pressure, even though they remain safe according to FDA (Nabors et al., 2016, p 6.).

Sugar avoidance has been regarded as a macro trend that will only continue to increase, with younger consumers avoiding synthetic sweeteners (Sterk, 2018). Younger consumers favor products with stevia as an ingredient. Further, a survey by Information Resources Inc. in 2017 showed that 58 % of consumers across generations were avoiding sugar, with 50 % avoiding adding any form of sugar to the beverages and food, 30% avoiding consuming products with sugar. 85 % of consumers avoiding sugar were doing so for health reasons while 58 for weight reasons. The survey concluded that sugar and Splenda purchases were expected to decline in the future while honey and stevia purchases will continue to rise.

In this regard, the increasing consumption of foods and beverages with sugar substitutes that have low calories will continue to increase the demand for low-calorie sweeteners. Due to increasing health awareness, the demand for low-calorie natural sweeteners will continue to rise while the growth of low-calorie synthetic sweeteners will decline.

Issues with Non-Nutritive Sweeteners (NNS)

Contrary to common belief, recent studies showed that long term use of NNS may increase weight gain, having unintended psychological, physiological or behavioral changes that hinder weight loss goals (Hill, Prokosch, Morin & Rodeheffer, 2014). One of the theory behind the evolution that led human to develop perception for sweet tastes is that the flavor is a reliable orosensory cue to a food's energy content as sweeter foods generally have denser carbohydrate contents thus packed with more energy (Hill, Prokosch, Morin & Rodeheffer, 2014). However, human may also have a cognitive system working in conjunction with the sensory system to regulate food intake based on sugar level. The study revealed that consumption of NNS sweetened food disrupts this pre-established link. In one of the experiments, volunteers who consumed NNS sweetened food has shorter response latencies to names of high-calorie food items; while another experiment revealed that volunteers who consumed NNS sweetened beverages were 2.93 times more susceptible to eating candy than those who consumed non-sweetened or sugar-sweetened food (Hill, Prokosch, Morin & Rodeheffer, 2014). These results indicate that consumption of NNS may disrupt the psychological food and energy balance, and implicitly encourage consumer to consume more food. In another fMRI study, researchers discovered that regular consumption of NNS can alter the neural pathways that are responsible for the hedonic response to food (Green & Murphy; Smeets et al.,2011). In other words, consumers do not get as much satisfaction from NNS as they do from sugar, causing them to ingest more food and facilitating eating disorder.

Of course, this cannot be seen as definitive argument, with many studies reaching different, (Griffioen-Roose et al, 2013) or contradicting conclusions (Appleton & Blundell, 2007). One of the hypothesis is that in the early stage of replacing sugar with NNS, consumers appear to reduce body weight due to lower intake of calories. Over time, NNS disrupts their psychological responses to sweet food and beverages (Hill, Prokosch, Morin & Rodeheffer, 2014). This process can be unconscious, as consumers may not obtain the same level of satisfaction as they do from sugar, and eat more food in attempt to reach higher satisfaction. Alternatively, this psychological and behavioural change may also be conscious. When consumers do not obtain the same amount of energy from NNS sweetened food, they consume more food to compensate. This behavior can be further explained by studies that showed participants experiencing more significant drop in blood glucose after consuming NNS, comparing with those who ingested sugar sweetened food (Hill, Prokosch, Morin & Rodeheffer, 2014).

Consumers, industry and the scientific communities are still far away from reaching a definitive answer and finding a perfect solution to reduce over-weight population without giving up on enjoying the sweet taste. Until this day, there is not a single synthetic sweetener that is capable of mimicking the flavor profile of real sugar perfectly, and there is no better solution to reduce obesity than simply living healthy.

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