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Sweeteners

R. Mathur

Department of Chemistry, Jai Narain Vyas University, Jodhpur-342003(Raj)India

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Abstract: Sweetness is one among the basic tastes of human being. It has been realized for centuries or more better from almost the age of human civilizations. Several natural materials with sweetness are known. These compounds vary in extent of their sweetness. Most of the natural sweeteners are carbohydrate or amino acid derived products. Many synthetic sweeteners have also come up during the last century. This article summarizes some of the common sweeteners.

Keywords: Sweeteners, carbohydrate, sugar, Cane-sugar or beat-sugar (sucrose), Glucose, Fructose, Lactose (milk-sugar), Maltose (a disaccharide of glucose), Tagatose.

INTRODUCTION

Just after birth a human child develops preference for sweet taste. This arises due to certain genetic considerations. Life sustaining mother's milk for a child contains sugar lactose, which imparts it a mild sweet taste. Thus a child establishes a life-long preference for sweet taste. Sweet taste instills in him a sense of enjoyment, security and well-being. Primates, the close evolutionary relatives of man also have a preference for sweet taste, as indicated by their preference for ripened, sweet fruits. Sweet taste is almost universally regarded as the most pleasant experience. Our reaction to sweet substances is an innate preference. Sugar is one of the most important raw materials used in food industry, further to its sweet taste its hypertensive solution decreases the freezing point of food; increases the boiling point and viscosity; helps yeast fermentation and improves the look and taste of food products¹⁻³.

Human preference for food, having certain specific flavor and taste (sweet and sweet-sour, in Hindi, *Khat-meetha*) is due to highly developed taste buds, which most animals' lack. The perception of

sweetness of food is transmitted to the human brain by the 'receptor-cells', localized on the surface of human tongue. Sensory perception due to any food-ingredient also depends on such factors as flavor, temperature and the presence of other food ingredients. An interesting, psychological bias regarding relative sweetness of chocolates made from the same paste, but having different geometrical shapes has been reported. A group of persons, who tasted round, square and triangular shaped chocolates, made from the same paste, found the round-shaped sweeter, while angular shaped bitter-sweet.

Sweeteners can be used to decrease energy, substitute the sweet taste, to decrease or maintain body weight. The risk of using additives is that after adding them to food products they become part of them. All the additives sold and used in products have passed a licensing process, nevertheless, we still hear about substances that are harmful to our health. Several novel studies suggest that sweetener consumption may be followed by increased food intake and can cause overweight or obesity, while other studies refute the decreased or unchanged ratings of hunger or food intake. As a result of consumers' negative feelings towards artificial sweeteners the demand for stevia, a natural non-caloric sweetener seems to be rapidly increasing. From the toxicological point of view sweeteners are the most examined and most controversial additives in the food industry.

Classification of Sweeteners: Sweeteners can be classified according to their origin; i.e. natural and synthetic. Natural sweeteners like cane-sugar (sucrose), glucose, and fructose are plants products, while lactose is an animal product. In chemical science, these are collectively referred as 'carbohydrates'. Some natural substances other than carbohydrate, e.g., the amino-acid glycine are also sweet (in Latin, 'gly' means sweet). There are many synthetic compounds, e.g. saccharine and aspartame, with sweet taste. Synthetic sweeteners generally have an intense sweet taste and these are called 'high potency sweeteners' (HPS). While carbohydrates produce metabolic-energy during digestion, saccharine is not metabolized and excreted as such. Hence it has zero metabolic energy. Amino-acids produced from aspartame (a dipeptide ester) are metabolized to produce weight for weight, energy nearly equal to sugar (~ 4 Kcal /g), but the amount of aspartame, necessary to produce same sweetness as produced by the sugar is far less. There are a few inorganic compounds e.g. acetate salts of lead and beryllium, having a sweet taste, but these are toxic. Ancient Romans used lead acetate as asweetener, but its use was eventually abandoned, when the high toxicity of lead compounds became known.

Sugar, an Energy-Source and Industrial Raw-Material: World-over sucrose is used as the most common sweetening agent in food, such as variety of *mithais*, desserts, cake, pie and pastries. It is a common table-top sweetener for milk, tea, coffee and beverages. As an industrial product it can be enzyme hydrolyzed into glucose and fructose. These mono-saccharides on hydrogenation produce sugar-alcohols (sorbitol and mannitol respectively). Sugar-alcohols are also edible sweeteners. Just like sugar these produce 'bulk and texture' in food, yet these produce fewer calories than sugar. Carbohydrates, fats and proteins are inter-convertible in human and animal metabolic systems. Thus, the exclusively meat eating animals (lion and tiger) also need blood-glucose as energy source, which they get by metabolic inter-conversion of fat and protein, into glucose. Besides sucrose, glucose and fructose naturally occur in fruits and honey. Before French and English colonizers established their rule in tropical regions, Europe knew sugary-test only in fruits and honey. Sugar production has been known and practiced in India, from very ancient times. Alexander, after conquering the Middle-East and Northern-India, on returning to Greece is reported to have mentioned about a bamboo-shaped, tall grass-form of a plant (sugar-cane or *Ganna* in Hindi) being cultivated in India. A sweet tasting fluid, squeezed out off it, produced sugar-crystals on drying. Elizabeth Abbot, in his book, 'Sugar: Bitter-Sweet History', has described, how the

technology of sugar refining and making sugar-cubes of size suitable for adding to a cup of tea was developed. During the eighteenth century the technology of sugar refining was not developed, and sugar-cane juice was simply evaporated to produce large, brownish sugar loafs, which were something like jaggery (*gur-ki-bheli* in Hindi). Sweetened-tea had become a favored beverage, particular in England. Brown sugar-loaf, imported from India, was smashed into irregular pieces to be added to a cup of tea. Some larger chunks of sugar were inconvenient to use and these had to be taken out of a tea-cup as sticky chumps, and dried for reuse. These difficulties ultimately helped in developing sugar refining technology in nineteenth century, and making sugar cube of size suitable for a normal cup of tea.

Beat-sugar is chemically identical to cane-sugar (sucrose)). Beat grows in colder regions of Europe. A German chemist, Andreas Maggot first isolated sugar from beet-root. The first beet-sugar factory was established in Silesia (1802). During Napoleon's regime, when Britain created a navel blocked for French West-Indies (source of sugar for France), beat-root based sugar industry flourished in Europe. In India, the only beet-root based sugar factory was established (mid-1940) in Shriganganager (Rajasthan), but the local farmers did not show much interest in beet-root agriculture, with the result that now it has become sugar-cane based.

Chemical-Structure and Sweetness-Correlation: Poly-hydroxyl compounds, which have hydroxyl groups on adjacent carbons atom, have sweet taste. Typical examples are ethylene-glycol (toxic), glycerol, xylitol, mannitol and sorbitol. Five and six carbon containing mono-saccharides are poly-hydroxyl compounds, which additionally have a ketonic or an aldehydic group. These exist as cyclic-acetals and have sweet-taste. The molecular feature common to the many different sweet tasting compounds has been sought for many years⁴. For the sugars, it was proposed⁵⁻⁸ that the sweet unit is the glycol group, and that intensity of sweetness varied inversely with the degree to which glycol OH groups appear to be intra molecularly hydrogen bonded.

It is now apparent that vicinal OH groups in the glycol unit need to be approximately gauche, or in a staggered conformation. Vicinal OH groups which are in the anti-conformation apparently are too far apart to cause sweet taste. Glycol OH groups which are eclipsed probably participate in an intra-molecular hydrogen bond which competitively inhibits interaction of glycol with the receptor site. Glycol conformational parameters, and the gross conformation of pyranose and furanose rings, have been used to explain the varying sweetness of the sugars⁵⁻⁸. Sugars have a strong affinity for water (hydrophilic). They produce high viscosity syrup in water, which give body and texture to beverages. Sugars leave a likable and lingering after-taste on tongue, for which they are preferred in food. This is believed to be due to their hydrogen-bonding to water in saliva.

Degree of Sweetness: Sweetness is measured on an arbitrary scale. This is based on an average of sweetness, as experienced by a group of persons. On this scale, the sweetness of can-sugar is taken as one. Mass for mass, glucose (sweetness unit, 0.6) is less sweet than sugar, while fructose is nearly twice as sweet (2.0 units). Some examples of carbohydrates and their relative sweetness are given in **Table-1**. It will be seen that different sugars have considerable difference in their sweetness. Thus, lactose present in milk at 3-4% concentration, hardly produce a perceptible sweet taste. High polymers of glucose (starch and cellulose) have a bland-taste. Synthetic sweetener, on mass for mass basis can be many thousand times sweeter than sugar.

Sugar Industry Byproducts: In manufacturing of crystalline sugar, the mother-liquor still contains a large portion of sugar, which cannot be crystallized economically, due to accumulation of non-sugar

impurities. Such liquor is easy to ferment into ethanol, which is recovered by fractional distillation of the fermented liquor. Alcohol thus produced is used as a solvent (sprit), in making alcoholic drinks and numerous organic compounds. Thus, to boost economy, alcohol-distilleries are frequently attached with sugar-plants.

Non-Sugar Sweeteners: For a class of persons, sugar has received a very bad name as a food ingredient. It has been blamed for obesity, cardiovascular diseases, diabetes, some form of cancer, dental-caries and even behavioral disorder. To some extent these popular blames remain, scientifically unfounded. Sugar substitutes are used for a number of reasons, e.g. to assist weight-loss by reducing caloric intake. Sugar substitutes are considered tooth-friendly and do not ferment by the micro-flora, which cause dental-plaque. By limiting sugar intake, blood-sugar level and diabetes mellitus is controlled. Sugar substitutes are of two types, i.e. the 'bulk sugar substitute' and HPS.

Modified Carbohydrate based Sweeteners (Bulk Sugar Substitutes): Inulin is a natural polysaccharide, having 40-60, β , (2 \rightarrow 1) linked D-fructose units, and terminating in α , (1 \rightarrow 2) linked D-glucose. On enzymatic depolymerization, it produces oligo-fructose sugar (OFS), having 4-6 fructose units. In certain plants (Jerusalem-Antichoke and chicory), hydrolysis of inulin occurs naturally to produce 2-4 fructose unit containing OFS. Due to the absence of β , (2 \rightarrow 1) link hydrolyzing enzymes in human digestive systems, OFS is not metabolized. It acts as a dietary fiber, in addition to being non-caloric, carbohydrate sweeteners. OFS is particularly used in combination with HPS (synthetic sweeteners), to produce a sweetness profile, very much similar to sucrose.

Tagatose is a ketohexose, similar to fructose, but unlike most of the natural D-sugars, it has L-configuration. It is a natural sweetener present at low concentration in many fruits, cacao and dairy products. G. Levin patented it as a non-calorie sweetener, which he synthesized (1988) from D-galactose. It is now produced commercially from galactose (hydrolysis product of lactose) by isomerization using calcium hydroxide as mild alkaline catalyst.

As a sweetener, it resembles fructose but because of its L-configuration, it is not recognized by human digestive-enzyme and acts as a non-calorie sweetener. Sugars-alcohols are found in some fruits and berries. Being uneconomical to extract from fruits, sugar-alcohols are produced by catalytic hydrogenation of natural sugars. Sugar-alcohols are less sweet than sucrose. Since the bulking properties of these are similar to sugar, these can be used as sugar substitute. Xylitol is a polyalcohol which can be used as a replacement for sugar and may be useful in diabetic diets, because it is considered as a low glycemic sweetener.

Non-Carbohydrate (HPS) from plants: Some non-carbohydrate constituents of plants have a sweet taste. A familiar example is that of liquorices root (Hindi, *Muleti* used with betel-leaf or *Pan*, Hindi). Sweet constituents of liquorices have been identified as tri-terpene glycosides (stevioside, mogroside) and glycyrrhizinic acid salt. Two plant proteins, thaumatin and brazzein have sweet taste.

These fragrant sweeteners are used in confections, i.e. chewing-gums and selected beverages. Thus, a number of blended sweeteners are now being used in specialty products, where these cause synergy in their sweetening action.

Synthetic Sweeteners (No or low calorie): It is pertinent to mention that no general structure-sweetness correlation can be drawn. When a HPS is used as a sugar substitute in beverages, it produces a sweet taste, but watery solution. In contrast to sucrose, a HPS does not give body (thickness and viscosity) to a

beverage. This is because they produce required sweetness at a very low concentration, and produce very low viscosity in a beverage. They do not leave a lasting after-taste. Some high potency sweeteners and their sweetness compared to sugar are shown in following table.

Table-1: Relative sweetness of some sugars.

Sugar	Sweetness
Cane-sugar or beat-sugar (sucrose)	1.0
Glucose	0.6
Fructose	2.0
Lactose (milk-sugar)	0.25
Maltose (a disaccharide of glucose)	0.6
Tagatose	2.0

Saccharine was the first artificial sweetener, to be synthesized in the year 1879 by Remsen and Fahlberg. Its sweet taste was discovered accidentally. Remsen, during his dinner at home found sweetness in all the things he ate. For this he had an argument with his wife, but later on he realized, the sweetness to be associate to his fingers. It was due to an organic compound, smeared on his fingers, with which he was working in his laboratory. A synthetic process for saccharin from phthalic-anhydride was developed in the year 1950, and currently saccharin is being synthesized by this process. Saccharine is 300-500 times sweeter as sucrose. It is added to toothpastes to improve their taste and to dietary foods, and beverages. It has a slight bitter aftertaste, which is minimized by blending it with other sweeteners. In larger doses saccharine is reported to cause bladder-cancer, as reported in a study (1960) on rats. Most countries permit the use of saccharin at a restricted level.

Sucralose, a No-Calorie Sweetener derived from Sugar: Sucralose was discovered in the year 1976 by scientists from Tate & Lyle Co. These scientists (Leslie Hough and Shashikant Phadnis), were working on a chlorinated sucrose derivatives. Phadnis was asked to 'test' a chlorinated sugar-derivative. Misunderstanding 'test' for 'taste' he found the compound to be exceptionally sweet. Sucralose is about 320-1,000 times sweeter than sugar, while it is nearly twice as sweet as saccharin, and three times as sweet as aspartame. It is stable over a wide range of pH and heat. Hence, it can be used in baked foods.

Aspartame: In the year 1965 James M. Schlatter discovered aspartame, while working on an anti-ulcer drug at Monsanto Co. in USA. He accidentally spilled a synthetic dipeptide ester on his hand, which he licked. Being derived from aspartic acid and phenylalanine, it was named aspartame. It had a sweet taste, similar to sugar, with no bitter side-taste like saccharine. It is a colorless, odorless, crystalline powder 150-200 times sweet compared to sugar. It is the most controversial intense sweetener, which converts into its three components into the body: aspartic acid, phenylalanine and methanol. According to some reports the metabolites eliminate through the normal metabolic pathways, but some researchers claim they may have a cumulative effect, and the consumption may be a hazard. Currently aspartame is one of the most widely used HPS, having trade names, NutraSweet, Equal and Sugar-Free. On blending with tamarind kernel polysaccharide, it produces a bulk and viscosity similar to sucrose and can be used in chocolates, marmalades, jams and in *Kheer*, *Rabari* and *Mithais*. Neotame and Alitame are other two peptide-sweeteners, similar to aspartame, which so far are not commercially used. Cyclamate and

Acesulfame-Kare two other synthetic sweeteners. As HPS and sugar substitute some more products are now being tested, for their advantages and adverse health-effect if any. To conclude therefore it can be said that, according to the Shakespearean quotation, -

‘All that glitters is not gold’, and to generalize it further, ‘All that tastes sweet may not be sugar. It can even be a poison’.

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***Corresponding author: R. Mathur;**

Department of Chemistry, Jai Naraian Vyas University,

Jodhpur, Rajasthan. India.