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Sugars: Types and Their Functional Properties in Food and Human Health

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Abstract

Sugar is a building blocks of carbohydrates and it is naturally found in many food such as fruit, milk, vegetables and grain, another kind of sugar is added sugar which can be founded in flavored yogurt, sweetened beverages, baked goods and cereals, and it is used widely in industry. There are several types of carbohydrates, including monosaccharide and polysaccharide, which have many properties, whether in terms of the food industry or nutritionally. In addition to main function of sugars as sweetness, they also have others roles in food industry such as preservation, antioxidants, enhance the color, flavor and texture. Many food which contain high added sugar, provides energy but it is already poor in another nutrients, so that will affect the balance of intake nutrients like mineral, vitamins and proteins. Therefore, the excessive intake of sugars has a very harmful effect, especially in critical stages such as childhood, pregnancy and aging. It is very important to moderate the intake of high-content sugar food to keep the body healthy. This article views types of sugars, their functions in food and their effects on the health.

Keywords

Sugars, Functional, Added Sugar, Health

1. Introduction

Sugar, which refers usually to sucrose, is natural and nontoxic, sweet testing, water soluble crystalline carbohydrates, and every 1 gram of sugar provide body 4K.calories. [1] The main source for sugar is the beet sugar or cane sugar; also there are several sources such as honey, corn syrup, fruits, and vegetables….etc. [2] The primary function of sugar in food products is to provide sweetness and energy, in addition, sugar plays a very important role in preservation, fermentation, color and texture. [3] At last years, the increase of consuming sugar leads to several disease especially obesity, cardiovascular disease and diabetes type 2, so food organizations issued strict instructions about determining the sugar intake in diets. [4]

2. History of Sugar

Since ancient times, sugar has been produced in India; it was expensive at first so honey was more often used for sweetening in the world. Sugarcane was a native of tropical South Asia and Southeast Asia, and people chewed it to extract its. [5] In Europe, sugar was found by the 1st century and used as an imported medicine not as a food. [6] Sugar stayed relatively unimportant until the Indians discovered methods to turning sugarcane juice into granulated crystals which is easier to store and to transport around the 5th century. [7] In the 15th century, Venice was the chief sugar refining and distribution centre in Europe. [8] China established its first sugarcane plantations in the 17^{th} century. Chinese documents confirm at least two missions to India, initiated in 647 AD, to obtain technology for sugar refining. [9] When Arab armies conquered the region, they carried away the knowledge of sugar manufacture and love of sugar as a food, condiment and medicine. In the early 700s Islamic armies had conquered much of Spain, bringing the culture of sugar with them. [10] In 19th century, sugar became more widely available, popular and considered a necessity. This evolution of taste and demand for sugar as an essential food ingredient unleashed major economic and social changes. [11]

3. Carbohydrate

Carbohydrates are one of the most plentiful biomolecules on Earth, sugar and starch are the essential part of food in most places of the world. The main roles of carbohydrate are as energy stores, fuels, metabolic intermediates and part of the structural framework of RNA and DNA. Carbohydrates are aldehydes, ketones with many hydroxyl groups, consist of carbon, oxygen and hydrogen, the empirical formula is (CH_2O) n and are classified as monosaccharide (which cannot be hydrolysed into smaller sub-units), disaccharide and polysaccharides. [12]

The monosaccharides, depending on the position of the carbonyl group, are classified as either aldoses or ketoses. Tetroses, pentoses, hexoses and heptoses have four, five, six and seven carbon atoms respectively. Monosaccharides, are the building blocks of carbohydrate chemistry. The common six-carbon sugars (hexoses) are D-glucose, D-fructose, and D-galactose. They all are aldohexoses, except D-fructose, which is a ketohexose. [12]

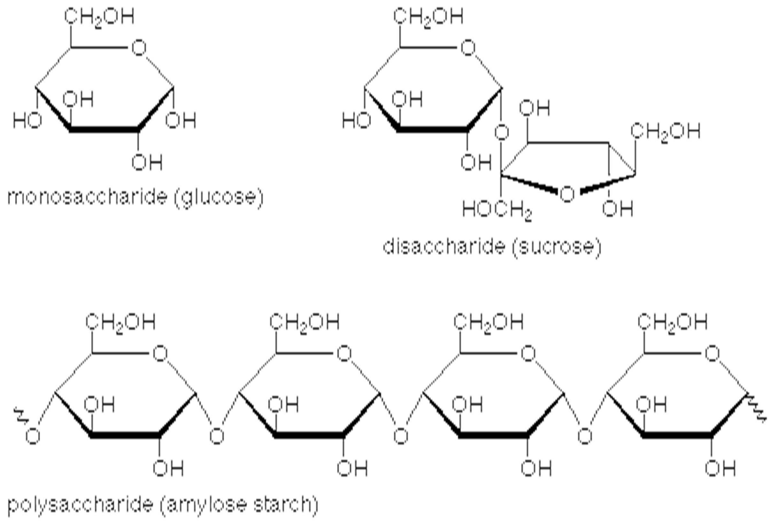

Figure 1. *Structure of monosaccharides, disaccharide and polysaccharide.*

3.1. Glucose

It is an aldohexose ($C_6H_{12}O_6$), since it contains an aldehyde group and six carbon atoms; there are two forms of it: open-chain (acyclic) and ring (cyclic) form. Glucose is soluble in water to give a neutral solution. Glucose is primary sources of fuel for cellular metabolism in the body. [13]

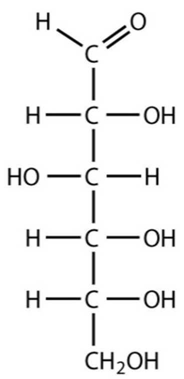

Figure 2. *Glucose Structure.*

3.2. Fructose

Fructose is present in much different type of fruit. Animals can convert glucose to fructose through sorbitol, Plants and some microbes can synthesise fructose from carbon dioxide and water. Fructose is a hexose monosaccharideb, can exist in a non-cyclic, straight chain form and the compound has a ketone group at carbon-2 in the chain, so there are two enantiomers of fructose L - and D –forms, but in nature, D -fructose is found almost exclusively. [12]

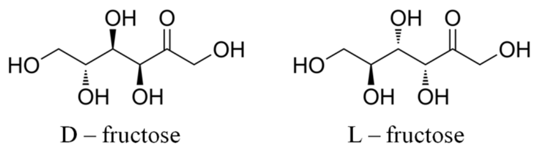

Figure 3. *Structure of D – fructose and L – fructose.*

3.3. Galactose

This sugar, contains six carbons (hexose), is an important monosaccharide and component of the disaccharide lactose, which is present in milk, D galactose is an epimer of D-glucose, as these sugars are only stereochemically different at carbon 4. It is an energetic source in cell metabolism. [12].

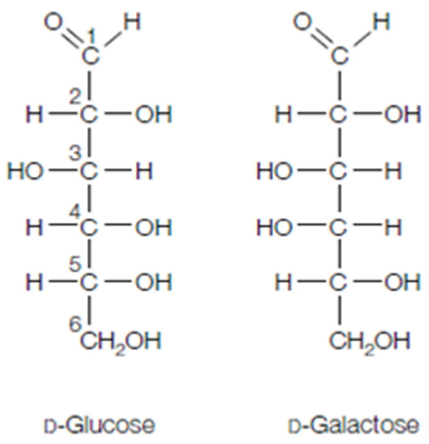

Figure 4. *D-galactose epimered from D-glucose.*

So the carbohydrate can be classified as:

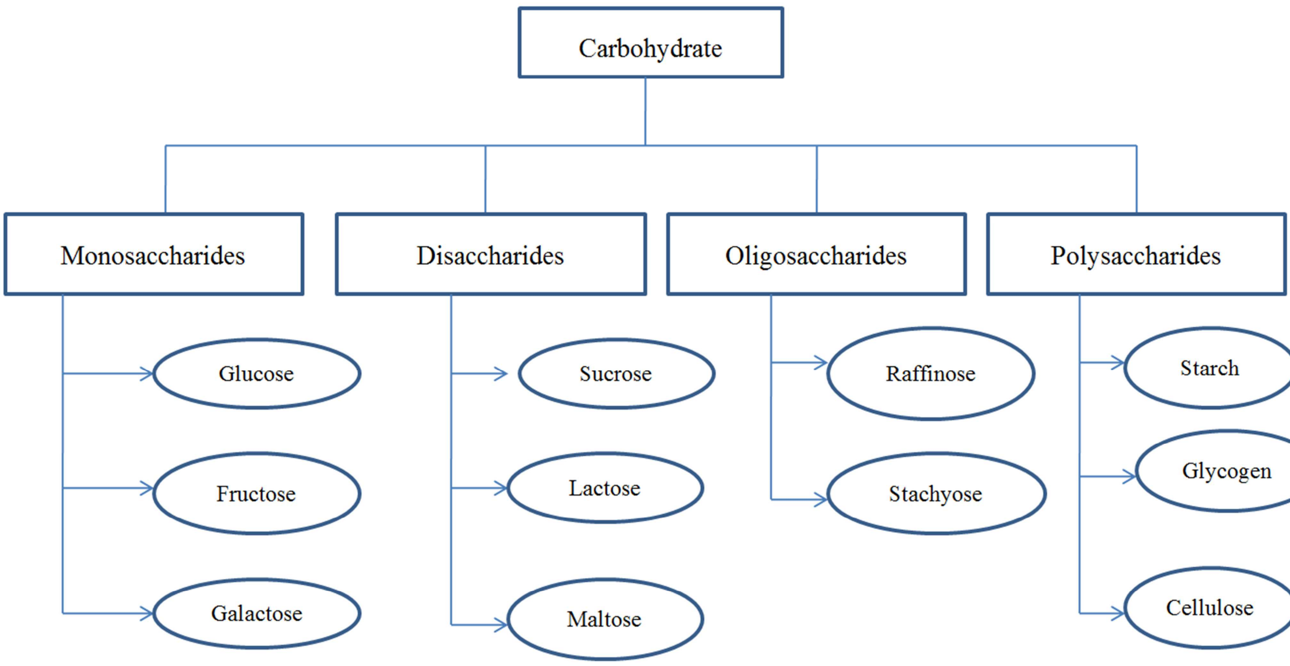

Figure 5. *Classification of carbohydrate.*

Monosaccharides are absorbed immediately in the small intestine without further chemical breakdown. Glucose is absorbed in the intestinal villi via co-transport with sodium ions; it then enters the capillary blood for eventual transport to the liver. More complex sugars, such as polysaccharides, oligosaccharides and disaccharides have to be broken down by various enzymes before they are absorbed in the small intestine. Salivary amylase which present in the saliva, breaks down polysaccharides into oligosaccharides. Once in the stomach, the acidity deactivates this enzyme. The polysaccharides that survived the salivary amylase are further broken down in the intestine by pancreatic amylase. Intestinal brush border enzymes further hydrolyze oligosaccharides and disaccharides into their constituent monosaccharides. Such enzymes include dextrinase, glucoamylase, maltase, sucrase and lactase. Chemical digestion ends in the small intestine because the colon does not secrete digestive enzymes. [14]

4. Source and Type of Sugars

There are several sources and types of sugar such as fruits, fruit juice concentrate, cane sugar, beet sugar, molasses, nectar, honey, corn sweetener, brown sugar, invert sugar ….. this article focuses on some of them.

4.1. Maple Syrup

It is made by cooking down the sap from maple trees; the sap contains 5% sucrose, with the remainder being comprised of other sugars (oligosaccharides). When it is condensed into the syrup form, it is made of 88-99% sucrose. A serving of maple syrup offers various vitamins and minerals, including calcium, potassium, and trace amounts of B vitamins, manganese, magnesium, and zinc. [15]

4.2. Molasses

It is the syrup (plant juice) separated from raw sugar beet or sugar cane during its processing into sucrose, and it is a by-product of sugar making. The predominant sugar is sucrose, which becomes more invert sugar with further processing. It contains very low levels of the minerals, calcium, and iron, although blackstrap molasses is the product of further sugar crystallization and contains a slightly higher mineral content. [16]

4.3. Starch Syrup Derivatives

Hydrogenation of glucose syrups results in products which, since they are nonfermentable and are less cariogenic, are used in manufacturing of sweet commodity products. Alkaline isomerization of maltose gives maltulose, which is sweeter than maltose, while hydrogenation yields maltitol in a mixture with maltotriose. [17]

4.4. Glucose-Fructose Syrup (High Fructose Corn Syrup, HFCS)

Glucose-fructose syrup is made by the enzymatic isomerization of glucose. Since an isomerization of only 42% is achieved, the production of higher concentrations (e.g., 55%) requires the addition of fructose. The fructose is obtained from the syrup by chromatographic enrichment. As a result of a comparable sweetening strength, HFCS replaces sugar in many sweet food. [17]

4.5. Table Sugar

The most important sweeteners (prevalent natural sweetener) is sucrose which called also table sugar, it is a disaccharide composed of one molecule glucose and one molecule fructose, typically got from sugar cane or sugar beets and refined to a white crystalline end product, and used as standard for the measurement of sweetness. [18]

4.6. Honey

Honey mainly consists of the carbohydrates fructose and glucose, and additionally contains approximately other 200 substances (other sugars, enzymes, amino acid and minerals). Several of these enzymes are related to the antimicrobial properties of honey, such as glucose oxidase and bee defensin-1 produced. Honey produces from the nectar, collected from flowers by honeybees. [19] Honey should never be given to any child under the age of one year because it may harbor spores of the bacteria that cause Infant Botulism, Clostridium botulinum. [17]

4.7. Sugar Alcohols

Polyols (sugar alcohols) occur naturally in fruits, vegetables and some fermented food, and can be chemically manufactured by hydrogenation of mono- or disaccharides. These saccharide derivatives used as sugar replacers for diabetics and in sugar free candies and confectionery. Polyols (e.g., xylitol, maltitol, Sorbitol, isomaltol) are poorly absorbed and therefore provide fewer calories and lower glycaemic responses, compared with sugars. [20] They are also digested and utilized differently than sugars, provide fewer calories, and promote negligible to very low degrees of postprandial glycemia depending on the polyol. [21]

5. Functional Properties of Sugar in Food

In addition to main role of sugars in providing sweet taste, there are large functions of sugars in food.

5.1. Sweetness

The most apparent sensory property of sugars such as glucose, fructose, and sucrose is their sweetness, Lactose (milk sugar) is the least sweet, whereas fructose is the sweetest sugar. Sugars are used as sweeteners in many kinds of food products.

5.2. Preservation

By absorbing free water and increasing osmotic pressure, sugar reduces water activity in a food system (e.g. jam), resulting in reduced microbial and mold growth as well as extending the storage life of food. Also sugar can preserve fruits, either in syrup with fruit such as apples, pears….. or in crystallized form where the preserved material is cooked in sugar to the point of crystallization and the resultant product is then stored dry. This method can be used for the skins of citrus fruit (candied peel), angelica and ginger. A modification of this process produces glace fruit such as glace cherries where the fruit is preserved in sugar but is then extracted from the syrup and sold, the sugar content of the fruit and the superficial coating of syrup maintain the preservation. Using of sugar is often combined with alcohol for preservation of luxury products such as fruit in brandy or other spirits. [22]

5.3. Flavor

Sugar plays an important and single role in contributing to the flavor of food by interacting with other components to enhance or lessen certain flavors. By adding a small amount of sugar to cooked vegetables and meat enhance the food's natural flavors, without making them taste sweet. [23] In sour applications such as beverages, jams and marmalades which all mixes of sweet and sour components, it is important to create a good balance between sourness and sweetness, which is often achieved by adding a mix of sugar and citric acid. In bitter applications, sugar is often used to moderate or disguise the bitterness (chocolate and coffee). [24]

5.4. Antioxidant Function

The hygroscopic nature of sugar produces a weak antioxidant effect by decreasing the availability of water that is otherwise required to potential oxidants. The antioxidant effect of sugar reduces rancidity; discolouration and deterioration of certain food products (e.g. canned fruits and baked goods). Also many early stage products of the Maillard reaction (in which sugar is involved) have been shown to work synergistically with other natural antioxidants (e.g. vitamin E) to prevent oxidation of lipids and proteins, extending the shelf life of food. [25]

5.5. Color

Sugar can give color to the food product by Millard reaction and Caramelisation: The Maillard reaction occurs between sugar and amino acids and gives rise to browning and flavoring in products such as bread, coffee, heated desserts and cakes. The end products of Maillard reaction include pigmentation, which causes coloration and aroma. [26] Caramelisation occurs when carbohydrates are exposed to high temperatures. The difference from Maillard reactions is no amino groups are involved. This reaction often occurs during the preparation of traditional sucrose syrups and caramels, which are extensively used in soft drinks, beer, confectionery and pastry products. [27]

5.6. Texture

The ability to interact with water and exist in amorphous and crystalline states gave the sugar functional properties to achieve desired texture in many food products. The molecules can reform either in a crystalline (from several micrometers to several millimeters) or an amorphous state (glassy, rubbery, gooey texture) depending on the processing of melted sugar. When the sugar added in enough amount to a solution, and bind water molecules, it will provide mouthfeel by increasing viscosity, and will decrease water activity, increase boiling temperature and decrease freezing temperature, so the behavior of proteins, starches, and hydrocolloids will change. [16] Cotton candy is an example glass state of sucrose, taffies and caramels candies are example for "rubbery" plasticized form. In these candies, sucrose can be replaced or partially substituted with other sugars or polyols. [28]

5.7. Fermentation

The sugar fermentation occurs by yeasts in anaerobic conditions, and produce carbon dioxide. This process is very important for bread making, beer and wine. In bread making, sugar plays important roles (in addition to taste), by leavening agent through the formation of carbon dioxide which causes bread dough to rise before and during baking, also the sugar has high affinity to bind to gluten so when dough is kneaded, a gluten structure of high elasticity forms, enabling the dough to stretch under the expansion of gases without collapsing. [16]

6. Sugars and Health

Sugar is critical for adequate metabolic function, to prevent stress on the body, and to avoid the depletion of critical cellular components. Certain tissues in the body, such as the brain and red blood cells, exclusively use sugar for energy. Humans have an appetite for sugary things, but in excess, sugary food can take a toll. Sugar substitutes, including the nonnutritive, artificial sweeteners and caloric sugar alcohols, intake of that product should be limited or eliminated from the diet. For example excessive levels of sugar alcohols may cause diarrhea. [16] Recently, the World Health Organization export a new set of revised dietary recommendations, the intake of free sugars should be less than 10% from total energy intake, because the free sugars threaten the nutrient quality of diets by providing significant energy without specific nutrients, thereby promoting a positive energy balance. [29] In addition, the sugars has been suggested as causative factor of many diseases, such as obesity, dental caries, diabetes mellitus, myocardial infarction, dyspepsia and peptic ulceration. [30] Also a dramatic rise in the prevalence of insulin resistance and type 2 diabetes mellitus has been paralleled by increasing dietary consumption of sugar. [31]

6.1. Obesity

Obesity and overweight are abnormal or excessive fat accumulation that may impair. Many causes may contribute to the obesity pandemic such as energy over-intake, easy availability to hyper-palatable food, loss physical inactivity, sugars and refined carbohydrates were proposed, with modest evidence, as more obesogenic than other nutrients. [32] Certain food such as added-sugars food may be capable of triggering addictive responses in some individuals, leading at last to compulsive and obsessive overeating. [33]

6.2. Sugar and Diabetes

Sugar-sweetened soft drinks may increase the risk of diabetes because of the large amounts of high-fructose corn syrup which causes rapidly raising blood glucose. Higher consumption of sugar sweetened beverages was associated with both greater weight gain and increased risk of type 2 diabetes, independent of known risk factors. Also sucrose sweetened soft drinks and food might increase risk of type 2 diabetes due to their readily absorbable carbohydrates. [31] Cola type soft drinks contain caramel coloring, which are rich in advanced glycation end-products that might increase insulin resistance. [34]

6.3. Sugar and Lipid

Diets high in sucrose produce large amounts of fructose and glucose which is transported to the liver via the hepatic portal vein. Fructose undergoes faster hepatic glycolysis than glucose because it bypasses the regulatory reaction catalyzed by phosphofructokinase, this allows fructose to overflow the pathways in the liver, leading to enhance fatty acid biosynthesis, increase fatty acids esterification and increase VLDL secretion and raise serum triacylglycerols and ultimately elevate LDL cholesterol. Sucrose and fructose have a greater effect in raising blood lipids, particularly triacylglycerols, than do other carbohydrates. [35]

6.4. Sugar and Cancer

This study showed the relationship between high pancreatic cancer and sucrose diet. The short term increase in pancreatic cancer risk associated with high available carbohydrate and low fat intake may be capturing dietary changes associated with subclinical disease. [34] A high sucrose diet acts as a promoter of cancer development and has been demonstrated to cause progression towards malignancy of tumors in the colon. [36] Added sugars positively associated with risk of esophageal adenocarcinoma, supplementary fructose associated with risk of small intestinal cancer. [37]

6.5. Sugar and Dental Health

Tooth decay or dental caries, promoted by oral bacteria, is a common cause of poor dental health, especially in children. The causes of dental caries are complex, such as nutritional status, oral hygiene, fluoride exposure, dietary habits, socioeconomic status and general health. [38] Although many people associate dental caries with sugars, all fermentable carbohydrates, including cooked starches, sugars in fruits, and added sugar. [39] Polyols are not fermentable by bacteria in the oral cavity and, thus, do not promote dental caries as sugars do so they are commonly found in chewing gum. [21]

7. Glycemic Index GI

The Glycemic Index (GI) is a scale that ranks carbohydrate-rich food by how much they raise blood glucose levels compared to a standard food. The standard food is glucose or white bread. To determine the GI, the duration and the extent of the increase in blood sugar after consumption of 50g of carbohydrate from food are measured. The reference value is the increase in blood sugar after the intake of 50g of glucose (GI = 100%). The GI of maltose (105) is higher, but the GI of sucrose (65), lactose (46) and fructose (23) is lower. GI is very important for patient of diabetes and other disease. [17]

8. Conclusion

In view of the above, the sugar can play many roles in food in addition to its main role as sweetens, and in order to be a full benefit it should be consumed in moderation to avoid adverse health effects. The high dose of sugar cause several diseases, so the attention on what we eat it is very important for healthy body, especially for children because sugary food are their favorite, in addition to the patients with diabetes and heart.

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