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Chemical Synthesis of Sugar in Sugar Industry

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ABSTRACT: Sugar is the generic name for sweet-tasting, soluble carbohydrates, many of which are used in food. Simple sugars, also called monosaccharides, include glucose, fructose, and galactose. Compound sugars, also called disaccharides or double sugars, are molecules made of two bonded monosaccharides; common examples are sucrose (glucose + fructose), lactose (glucose + galactose), and maltose (two molecules of glucose). White sugar is a refined form of sucrose. In the body, compound sugars are hydrolysed into simple sugars.Longer chains of monosaccharides (>2) are not regarded as sugars, and are called oligosaccharides or polysaccharides. Starch is a glucose polymer found in plants, the most abundant source of energy in human food. Some other chemical substances, such as glycerol and sugar alcohols, may have a sweet taste, but are not classified as sugar.Sugars are found in the tissues of most plants.[26] Honey and fruits are abundant natural sources of simple sugars. Sucrose is especially concentrated in sugarcane and sugar beet, making them ideal for efficient commercial extraction to make refined sugar. In 2015, the combined world production of those two crops was about two billion tonnes. Maltose may be produced by malting grain. Lactose is the only sugar that cannot be extracted from plants. It can only be found in milk, including human breast milk, and in some dairy products. A cheap source of sugar is corn syrup, industrially produced by converting corn starch into sugars, such as maltose, fructose and glucose.Sucrose is used in prepared foods (e.g. cookies and cakes), is sometimes added to commercially available processed food and beverages, and may be used by people as a sweetener for foods (e.g. toast and cereal) and beverages (e.g. coffee and tea). The average person consumes about 24 kilograms (53 pounds) of sugar each year, with North and South Americans consuming up to 50 kg (110 lb) and Africans consuming under 20 kg (44 lb).[1]As sugar consumption grew in the latter part of the 20th century, researchers began to examine whether a diet high in sugar, especially refined sugar, was damaging to human health. Excessive consumption of sugar has been implicated in the onset of obesity, diabetes, cardiovascular disease, and tooth decay. Numerous studies have tried to clarify those implications, but with varying results, mainly because of the difficulty of finding populations for use as controls that consume little or no sugar. In 2015, the World Health Organization strongly recommended that adults and children reduce their intake of free sugars to less than 10%, and encouraged a reduction to below 5%, of their total energy intake.[2]

KEYWORDS: sugar, consumption, chemical, commercial, industry, extraction, processing, WHO

I. INTRODUCTION

Scientifically, *sugar* loosely refers to a number of carbohydrates, such as monosaccharides, disaccharides, or oligosaccharides. Monosaccharides are also called "simple sugars", the most important being glucose. Most monosaccharides have a formula that conforms to $C_nH_{2n}O_n$ with n between 3 and 7 (deoxyribose being an exception). Glucose has the molecular formula $C_6H_{12}O_6$.[1] The names of typical sugars end with *-ose*, as in "glucose" and "fructose". Sometimes such words may also refer to any types of carbohydrates soluble in water. The acyclic mono- and disaccharides contain either aldehyde groups or ketone groups. These carbon-oxygen double bonds (C=O) [27]are the reactive centers.[2] All saccharides with more than one ring in their structure result from two or more monosaccharides joined by glycosidic bonds with the resultant loss of a molecule of water (H_2O) per bond.[64]

Monosaccharides in a closed-chain form can form glycosidic bonds with other monosaccharides, creating disaccharides (such as sucrose) and polysaccharides (such as starch or cellulose). Enzymes must hydrolyze or otherwise break these glycosidic bonds before such compounds become metabolized.[28] After digestion and absorption the principal monosaccharides present in the blood and internal tissues include glucose, fructose, and galactose. Many pentoses and hexoses can form ring structures.[3] In these closed-chain forms, the aldehyde or ketone group

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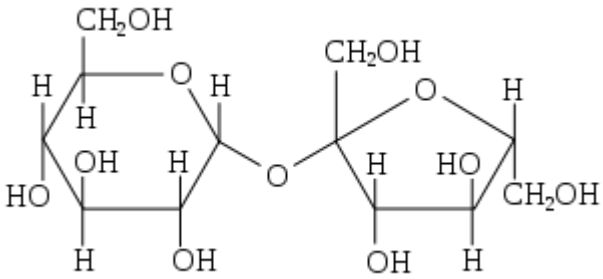
remains non-free, so many of the reactions typical of these groups cannot occur. Glucose in solution exists mostly in the ring form at equilibrium, with less than 0.1% of the molecules in the open-chain form.[64]



Sucrose

In November 2013, scientists reported detecting, for the first time, sugar molecules, including ribose, in meteorites, suggesting that chemical processes on asteroids can produce some fundamentally essential bio-ingredients important to life, and supporting the notion of an RNA World prior to a DNA-based origin of life on Earth, and possibly, as well, the notion of panspermia.[65][66]

Biopolymers of sugars are common in nature. Through photosynthesis, plants produce glyceraldehyde-3-phosphate (G3P), a phosphated 3-carbon sugar that is used by the cell to make monosaccharides such as glucose ($C_6H_{12}O_6$) or (as in cane and beet) sucrose ($C_{12}H_{22}O_{11}$). Monosaccharides may be further converted into structural polysaccharides such as cellulose and pectin for cell wall construction or into energy reserves in the form of storage polysaccharides such as starch or inulin. Starch, consisting of two different polymers of glucose, is a readily degradable form of chemical energy stored by cells[4], and can be converted to other types of energy.[64] Another polymer of glucose is cellulose, which is a linear chain composed of several hundred or thousand glucose units. It is used by plants as a structural component in their cell walls. Humans can digest cellulose only to a very limited extent, though ruminants can do so with the help of symbiotic bacteria in their gut.[67] DNA and RNA are built up of the monosaccharides deoxyribose and ribose, respectively. Deoxyribose[5] has the formula $C_5H_{10}O_4$ and ribose the formula $C_5H_{10}O_5$.[68]

Because sugars burn easily when exposed to flame, the handling of sugars risks dust explosion. The risk of explosion is higher when the sugar has been milled to superfine texture, such as for use in chewing gum.[69] The 2008 Georgia sugar refinery explosion, which killed 14 people and injured 36, and destroyed most of the refinery, was caused by the ignition of sugar dust.[70]

In its culinary use, exposing sugar to heat causes caramelization.[6] As the process occurs, volatile chemicals such as diacetyl are released, producing the characteristic caramel flavor.[71]

Monosaccharides

Fructose, galactose, and glucose are all simple sugars, monosaccharides, with the general formula $C_6H_{12}O_6$. They have five hydroxyl groups (−OH) and a carbonyl group (C=O) and are cyclic when dissolved in water. They each exist as several isomers with dextro- and laevo-rotatory forms that cause polarized light to diverge to the right or the left.[72]

- Fructose, or fruit sugar, occurs naturally in fruits, some root vegetables, cane sugar and honey and is the sweetest of the sugars. It is one of the components of sucrose or table sugar. It is used as a high-fructose syrup, which is manufactured from hydrolyzed corn starch that has been processed to yield corn syrup, with enzymes then added to convert part of the glucose into fructose.[73]
- Galactose generally does not occur in the free state but is a constituent with glucose of the disaccharide lactose or milk sugar. It is less sweet than glucose. It is a component of the antigens found on the surface of red blood cells that determine blood groups.[74]
- Glucose occurs naturally in fruits and plant juices and is the primary product of photosynthesis. Starch is converted into glucose during digestion, and glucose is the form of sugar that is transported around the bodies of

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animals in the bloodstream. Although in principle there are two enantiomers of glucose[7] (mirror images one of the other), naturally occurring glucose is D-glucose. This is also called dextrose,[29] or *grape sugar* because drying grape juice produces crystals of dextrose that can be sieved from the other components.[75] Glucose syrup is a liquid form of glucose that is widely used in the manufacture of foodstuffs. It can be manufactured from starch by enzymatic hydrolysis.[76] For example, corn syrup, which is produced commercially by breaking down maize starch, is one common source of purified dextrose.[77] However, dextrose is naturally present in many unprocessed, whole foods, including honey and fruits such as grapes.[78]

Disaccharides

Lactose, maltose, and sucrose are all compound sugars, disaccharides, with the general formula $C_{12}H_{22}O_{11}$. They are formed by the combination of two monosaccharide molecules with the exclusion of a molecule of water.[72]

- Lactose is the naturally occurring sugar found in milk. A molecule of lactose is formed by the combination of a molecule of galactose with a molecule of glucose. It is broken down when consumed into its constituent parts by the enzyme lactase during digestion. Children have this enzyme but some adults no longer form it and they are unable to digest lactose.[79]
- Maltose is formed during the germination of certain grains, the most notable being barley, which is converted into malt, the source of the sugar's name. A molecule of maltose is formed by the combination of two molecules of glucose. It is less sweet than glucose, fructose or sucrose.[72] It is formed in the body during the digestion of starch by the enzyme amylase and is itself broken down during digestion by the enzyme maltase.[80]
- Sucrose is found in the stems of sugarcane and roots of sugar beet. It also occurs naturally alongside fructose and glucose in other plants, in particular fruits and some roots such as carrots. The different proportions of sugars found in these foods determines the range of sweetness experienced when eating them.[72] A molecule of sucrose is formed by the combination of a molecule of glucose with a molecule of fructose. After being eaten, sucrose is split into its constituent parts during digestion by a number[30] of enzymes known as sucrases.[81]

II. DISCUSSION

Global production of sugarcane in 2014 was 1.9 billion tonnes, with Brazil producing 40% of the world total and India 20% [8]

Sugarcane refers to any of several species, or their hybrids, of giant grasses in the genus *Saccharum* in the family Poaceae. [58]They have been cultivated in tropical climates in the Indian subcontinent and Southeast Asia over centuries for the sucrose found in their stems.[5] A great expansion in sugarcane production took place in the 18th century with the establishment of slave plantations in the Americas.[9] The use of slavery for the labor-intensive process resulted in sugar production, enabling prices cheap enough for most people to buy. Mechanization reduced some labor needs, but in the 21st century[57], cultivation and production relied on low-wage laborers. Sugar cane requires a frost-free climate with sufficient rainfall during the growing season to make full use of the plant's substantial growth potential. [31]The crop is harvested mechanically or by hand, chopped into lengths and conveyed rapidly to the processing plant (commonly known as a sugar mill) where it is either milled and the juice extracted with water or extracted by diffusion.[86] The juice is clarified with lime and heated to destroy enzymes.[10] The resulting thin syrup is concentrated in a series of evaporators, after which further water is removed. [56]The resulting supersaturated solution is seeded with sugar crystals, facilitating crystal formation and drying.[86] Molasses is a by-product of the process and the fiber from the stems, known as bagasse,[86] is burned to provide energy for the sugar extraction process. The crystals of raw sugar have a sticky brown coating and either can be used as they are, can be bleached by sulfur dioxide, or can be treated in a carbonatation process to produce a whiter product.[86] About 2,500 litres (660 US gal) of irrigation water is needed for every one kilogram (2.2 pounds) of sugar produced.[87] In 2014, global production of sugar beets was 253 million tonnes, led by Russia with 13% of the world total. The sugar beet became a major source of sugar in the 19th century when methods for extracting the sugar became available. It is a biennial plant,[89] a cultivated variety of *Beta vulgaris* in the family Amaranthaceae, the tuberous root of which contains a high proportion of sucrose. It is cultivated

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as a root crop in temperate regions with adequate rainfall and requires a fertile soil. The crop is harvested mechanically in the autumn and the crown of leaves and excess soil removed. [55]The roots do not deteriorate rapidly and may be left in the field for some weeks before being transported to the processing plant where the crop is washed and sliced, and the sugar extracted by diffusion.[90] Milk of lime is added to the raw juice with calcium carbonate.[11] After water is evaporated by boiling the syrup under a vacuum, the syrup is cooled and seeded with sugar crystals. The white sugar that crystallizes can be separated in a centrifuge and dried, requiring no further refining.[90] Refined sugar is made from raw sugar that has undergone a refining process to remove the molasses.[91][92] Raw sugar is sucrose which is extracted from sugarcane or sugar beet. While raw sugar can be consumed, the refining process removes unwanted tastes and results in refined sugar or white sugar.[93][94]

The sugar may be transported in bulk to the country where it will be used and the refining process often takes place there. The first stage is known as affination and involves immersing the sugar crystals in a concentrated syrup that softens and removes the sticky brown coating without dissolving them.[13] The crystals are then separated from the liquor and dissolved in water. The resulting syrup is treated either by a carbonatation[54] or by a phosphatation process. Both involve the precipitation of a fine solid in the syrup and when this is filtered out, many of the impurities are removed at the same time.[32] Removal of color is achieved by using either a granular activated carbon or an ion-exchange resin.[12] The sugar syrup is concentrated by boiling and then cooled and seeded with sugar crystals, causing the sugar to crystallize out. The liquor is spun off in a centrifuge and the white crystals are dried in hot air and ready to be packaged or used. The surplus liquor is made into refiners' molasses.[95]

The International Commission for Uniform Methods of Sugar Analysis sets standards for the measurement of the purity of refined sugar, known as ICUMSA numbers; lower numbers indicate a higher level of purity in the refined sugar.[96]

Refined sugar is widely used for industrial needs for higher quality. Refined sugar is purer (ICUMSA below 300) than raw sugar[33] (ICUMSA over 1,500).[97] The level of purity associated with the colors of sugar, expressed by standard number ICUMSA, the smaller ICUMSA numbers indicate the higher purity of sugar.[97]

III. RESULTS

Brown and white granulated sugar are 97% to nearly 100% carbohydrates, respectively, with less than 2% water, and no dietary fiber, protein or fat (table). Brown sugar contains a moderate amount of iron (15% of the Reference Daily Intake in a 100 gram amount, see table), but a typical serving of 4 grams (one teaspoon), would provide 15 calories[53] and a negligible amount of iron or any other nutrient.[107] Because brown sugar contains 5–10% molasses reintroduced during processing, its value to some consumers is a richer flavor than white sugar.[108] Sugar refiners and manufacturers of sugary foods and drinks have sought to influence medical research and public health recommendations,[109][110] with substantial and largely clandestine spending documented from the 1960s to 2015.[111][112][113][114] The results of research [35]on the health effects of sugary food and drink differ significantly, depending on whether the researcher has financial ties to the food and drink industry.[115][116][117] A 2013 medical review concluded that "unhealthy commodity industries should have no role in the formation of national or international NCD [non-communicable disease] policy".[118]

There have been similar efforts to steer coverage of sugar-related health information in popular media, including news media and social media.[119][120][121]

Sugarcane is broadly classified into three varieties viz., Early, General, and Unapproved. Typically sugarcane seeds are sown in the months of February and October every year. The first seed growth is known as Plant and subsequent growth after harvesting from the stem is known as Ratoon. The Early variety has more sugar content than the General variety.[14]

All farmers within the command area of our Mills are provided with a calendar which tells them when they can expect a Mill Supply Ticket (Purchy) against which they will deliver their produce.[36]

The farmers then harvest the cane and transport it to the mill. Sometimes the cane is also bought at the mill's own centers within the command area from where it is then transported in trucks or via rail to the mill.

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Cane is weighed using an electronic weigh bridge and unloaded into cane carriers. It is then prepared for milling by knives and shredders. Sugarcane juice is then extracted by pressing the prepared cane using mills consisting of three rollers.[52]

Extracted juice mixed with water is weighed and sent to the boiling house for further processing. Residual bagasse is sent to boilers for use as fuel for steam generation.[37]

This juice is heated and then treated with milk of lime and Sulphur Dioxide. The treated juice is heated further and sent to clarifiers for continuous settling. The settled mud is filtered by vacuum filters and clear juice is returned for further processing while the Oliver cake is sent out.[15]

The clear juice is evaporated to a syrup, bleached by Sulphur Dioxide and sent to vacuum pans for further concentration and forming sugar grains. Crystals are broken into a desired size and the crystallized mass is then dropped in the crystallizers to exhaust the mother liquor of its sugar to the extent possible. This is then centrifuged for separating the crystals from molasses. The molasses is boiled again for further crystallization.[51]

Thus, the original syrup is desugarised progressively (usually thrice) until finally a viscous liquid is obtained from which sugar can no longer be recovered. This liquid, which is called final molasses, is sent to the distillery for making alcohol.[38]

The sugar separated from molasses in the centrifuge is dried, bagged, weighed, and sent to storage houses.

Sugar is made in different sizes and assigned grades i.e. large, medium and small.[16]Sugar manufacturing can be explained in the following steps:

Cleaning:

Post harvesting, as soon as the canes or beets arrive at the plant they are cleaned. [39] It can be either by placing them in rotating drums or on conveyor belts and spraying water on them.[50] It is critical to remove mud or any other kind of unwanted material before juicing.[17]

Cleaning

Milling:

This step involves breaking the cane's hard structure and extracting the juice from it.

In most cases, shredders or revolving knives are used along with three roller mills.[40] Once the cane is processed in one conveyor belt it is passed on to the other through conveyor belts to extract more juice. [49] But water is sprinkled before doing so to extract more juice. The cane waste removed in the end after milling is called bagasse.[18]

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Milling

Clarification:

The process involves removing impurities from the sugar cane or sugar beet juice.[41] It is mostly done by adding lime to it to neutralise the organic acids present in it. The solution is later heated up to 95°C. The heating helps in coagulation and the impurities settle in the bottom, which is then removed. [19]

Clarification

Evaporation:

The water in the juice needs to be reduced. The solution is evaporated to achieve the same. [42]In this step, almost two-thirds of water is removed. The solution is passed through a multiple-effect evaporator. Close to 2/3rd of water is removed through this process.[43] They are passed through a multiple-effect evaporator. The multi-effect evaporator is a series of usually five evaporators.[20]

Evaporation

Crystallization:

There is a need to further reduce the water content so that sugar crystals are formed. The solution is further heated in vacuum pans until it reaches supersaturation. [44]They are then moved from the pan to the crystallization tank.

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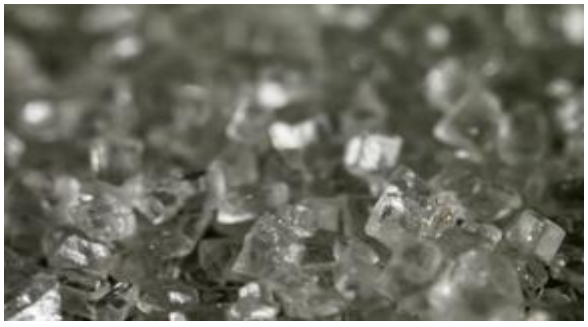
Meanwhile, some small grains of sugar are also added, so that they can act as nuclei for crystal formation. It is known as seeding. [21]

Crystallization

Separation of crystals:

The crystals are separated and the leftover material is called molasses, which is a by-product of the manufacturing process.[45] Centrifugal force is used to remove them and they are dried by passing them through a hot pipe. [22]



Sugar Crystals

Before sending the sugar to the market for sale, in most cases, it is refined. Refining involves removing further impurities.[46] The process of sugar making is thus heavily driven by crushing the sugar cane or sugar beet, removing impurities and water and forming crystals.[23]

IV. CONCLUSIONS

Mill sanitation is an important factor in quality control measures. Bacteriologists have shown that a small amount of sour bagasse can infect the whole stream of warm juice flowing over it.[48] Modern mills have self-cleaning troughs with a slope designed in such a way that bagasse does not hold up but flows out with the juice stream. Strict measures are taken for insect and pest controls.[24]

Because cane spoils relatively quickly, great steps have been taken to automate the methods of transportation and get the cane to the mills as quickly as possible. Maintaining the high quality[47] of the end-product means storing brown and yellow refined sugars (which contain two percent to five percent moisture) in a cool and relatively moist atmosphere, so that they continue to retain their moisture and do not become hard.[25]

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28. ^ Strong, 194
29. ^ Frankopan, 200. "By the time Columbus set sail, Madeira alone was producing more than 3 million pounds in weight of sugar per year—albeit at the cost of what one scholar has described as early modern 'ecocide,' as forests

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were cleared and non-native animal species like rabbits and rats multiplied in such numbers that they were seen as a form of divine punishment."

30. ^ Strong, 194–195, 195 quoted
31. ^ Strong, 75
32. ^ Strong, 133–134, 195–197
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