Molecule of the Month

Sucrose – A Sweet and Useful Sugar

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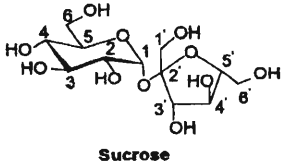
Which is the most abundantly produced organic chemical in the pure form, as a single chemical entity? If you think the answer is a petrochemical product or a polymer, think again. The chemical is sucrose or common sugar, with an annual world production exceeding 100 million tons. India is the world's largest producer, with an output of over 10 million tons per year.

Chemically, sucrose belongs to a family of compounds known as carbohydrates, or more trivially, sugars. As the name itself suggests, many of the members of this family have the empirical formula $C_m(H_2O)_n$, thus leading to their formulation as hydrates of carbon. Today, carbohydrates are classified as polyhydroxy aldehydes or ketones as well as their derivatives (*Structure* 1).

Structure 1.

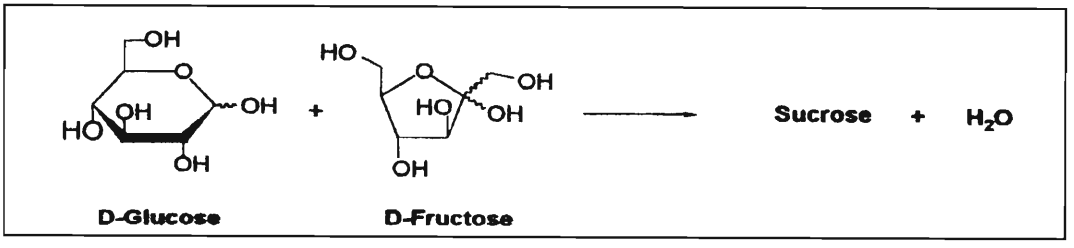


Sucrose

Sucrose has the molecular formula $C_{12}H_{22}O_{11}$. It is a disaccharide, as mild acid hydrolysis converts it to two simpler sugars. D-glucose and D-fructose, both have the molecular formula $C_6H_{12}O_6$. As glucose and fructose cannot be hydrolyzed further by acid, they are referred to as monosaccharides. Sucrose, then, is formed from D-glucose and D-fructose by loss of a water molecule. Chemically, this reaction can be depicted as shown in *Scheme* 1.

Commercially, sucrose is obtained from two renewable sources – sugarcane and sugarbeet. While sugarcane is a tropical crop, sugarbeet is an important source of sucrose in temperate

Scheme 1.



countries. In general terms, the manufacturing process consists of crushing the cane or beet to obtain the raw juice, which is then clarified, decolourized, concentrated and crystallized to yield sucrose. On the average, the recovery of sucrose from sugarcane ranges from 9 to 11%.

Lipophilicity: The property by which a substance is attracted to lipids (fats).
Cariogen: A substance, which induces caries (dental decay) by attacking the enamel of teeth.

Sucrose is well known as a sweetener. When ingested, it is readily hydrolyzed to glucose and fructose, which serve as important sources of energy. Other foods rich in starch like rice and wheat also produce glucose on digestion, but at a much slower rate. Pure sucrose is a poor nutrient precisely because it is a pure compound! It has no minerals unlike jaggery or gur and, of course, contains no proteins or fat. In addition, it is also responsible for tooth decay.

A lot of effort has been put in to understand why sucrose tastes sweet. The tongue has receptors for different tastes and if a suitable molecule binds to the appropriate receptor, we experience the corresponding taste. For a compound to have a sweet taste, the following structural features are needed:

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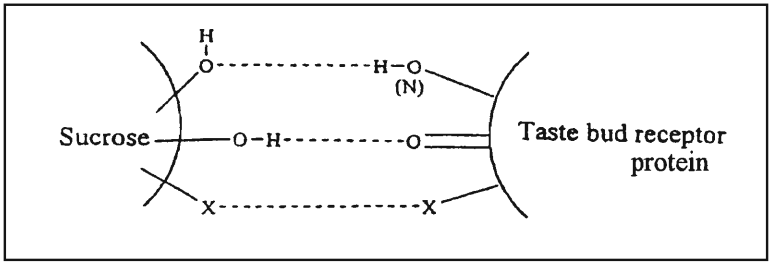
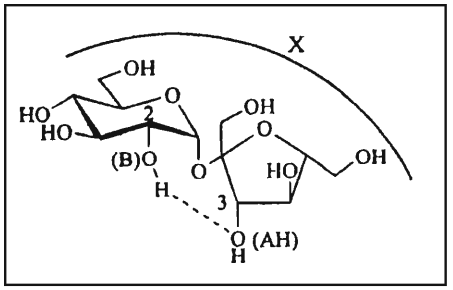
(1) Two electronegative atoms A & B separated by 2.5 to 4.0, with a hydrogen atom attached to A, giving rise to the unit. AH...B. This unit interacts in a complementary fashion with a suitable amino acid of the protein, such as serine or threonine, which contain a carbonyl group (acceptor) as well as a hydroxyl or amino group (donor).

(2) The lipophilic portion of sucrose serves to anchor the molecule to the receptor, completing the three-point interaction. All this is shown in *Structure* 2 schematically.



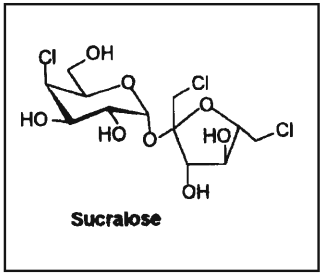
Structure 2.



Structure 3.

In the case of sucrose, AH and B have been identified as the hydroxyl group at C-3 of the fructose moiety and the oxygen at C-2 of the glucose ring, respectively. This information has been obtained from proton NMR spectral studies indicating the proximity of the two-hydroxyl groups. In addition, conversion of the hydroxyl group at C-3 of fructose to its acetate results in loss of sweetness, clearly identifying as the 'AH' group. The lipophilic face corresponds to the top face of sucrose and serves to bind the sugar to the receptor protein (*Structure* 3).

Structure 4.

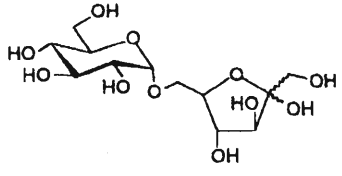


According to this hypothesis, increasingly the lipophilicity of sucrose by replacing the hydroxyl groups at the C-4 and C-6 positions of glucose and C-1 and C-6 positions of fructose should enhance the sweetness. This is precisely what happens when the hydroxyl groups at C-4 of glucose and C-1 and C-6 of fructose are replaced by chlorine. The resulting molecule, called sucralose, is 650 times sweeter than sucrose (*Structure* 4).

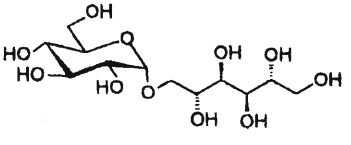
One important application utilizing sucrose is its conversion by enzymatic means to other sweeteners, which are less cariogenic. Some of them are shown below. Although they are not as sweet as sucrose, their greater stability towards acid catalyzed hydrolysis in the mouth make them less harmful in terms of dental decay (*Structure* 5).

A second important application of sucrose is in the manufacture of 'synthetic fats'. The health hazards associated with excessive intake of fats have been well documented. Sucrose polyesters

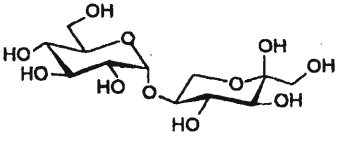
Structure 5.



Isomaltulose

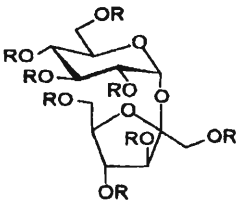


Isomalt



Leucrose

Relative sweetness (Sucrose=100)	42	45-50	40-50



R=H or R=$CH_3(CH_2)_nCO$-

n=6 to 20

Sucrose Polyester (SPE)

Structure 6.

(*Structure* 6) of long chain fatty acids are not hydrolyzed in the body and hence they provide no fat and are of very low calorific value. Another advantage they possess is their ability to reduce cholesterol levels due to high solubility of cholesterol in them. A disadvantage is the loss of lipophilic vitamins through the same route.

Today, sucrose is attracting attention from chemists for reasons other than its sweet taste. It is being increasingly viewed as a renewable source of organic chemicals. Some of the uses of sucrose are as building blocks for hydrophilic polymers, gels and surfactants and as builders and bleaching boosters in detergents. An important advantage with these compounds is that they are generally biodegradable and hence environmentally benign. Sucrose derivatives have also been explored as water-soluble conjugating agents for many drugs, which are insoluble or poorly soluble in water.

Next time you eat something sweet, spare a thought for that wonder molecule sucrose. Not only does it have a sweet taste, but, in addition, it also has the potential to serve as a versatile renewable and green source of a whole host of organic chemicals we use in our everyday life.

Suggested Reading

[1] *Carbohydrates as Organic Raw Materials*, Ed F W Lichtenthalser, VCH Publishers, Weinheim, 1991.

[2] *Carbohydrates as Organic Raw Materials* II, Ed. G Descotes, VCH Publishers, Weinheim, 1993.

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