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Mini Review

Sugar Alcohols: Chemical Structures, Manufacturing, Properties and Applications

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Received: May 17, 2016; **Published:** June 01, 2016

Abstract

Sugar alcohols (Polyols), are currently used as bulk sweeteners in reduced calorie foods. They are part of human diet for thousands of years and are present in fruits such as pears, melons, and grapes as well as mushrooms and fermentation foods (wine, soy sauce and cheese). The most common sugar alcohols that are available in the market are sorbitol, mannitol, xylitol, erythritol, isomalt, lactitol, maltitol, and hydrogenated starch hydrolysates (HSH). Sugar alcohols are believed to be good sugar substitutes for people with diabetes plus they do not contribute to dental caries (cavities). Their caloric value are generally half that of sugar sucrose. Plus they have a very low glycemic index, which are great for controlling blood sugar levels. Chemical structures of sugar alcohols are a hybrid between sugar molecule and an alcohol molecule. However they are neither a sugar nor an alcohol.

Keywords: *Sorbitol; Mannitol; Xylitol; Erythritol; Isomalt; Lactitol; Maltitol; Hydrogenated starch hydrolysates; Glycemic Index; Diabetes; Sweeteners; Dental Caries; FDA*

Introduction

Sugar alcohols are also know by the name polyols and can be classified as carbohydrates. They are naturally occurs in many fruits and vegetables, but they are widely consumed in sugar-free and reduced-sugar foods. The sweetness of sugar alcohols varies from 25% to 100% comparing to the table sugar sucrose. The reason sugar alcohols are used in sugar-free foods because they are slowly and incompletely absorbed in the body and use almost zero insulin to be converted into energy. Plus sugar alcohols partially passes into the bloodstream, through the small intestine and the rest passes from low intestine into the large intestine is fermented by colonic microbes.

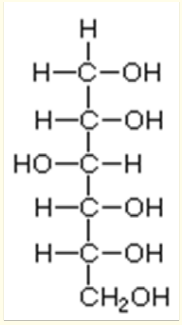
Sugar alcohols are found in a vast array of sugar-free food products items like candy, gum, ice cream, baked good, and fruit spreads. They can also be found in oral hygiene products like toothpaste, mouthwashes and breath mints; they are also found in medicines like cough syrups and lozenges; and most importantly they can be found in lots of sports nutrition products like protein powders, pre-workout supplements, and low-carb products.

Sugar alcohols are classified by chemical structure into three groups, these groups are:

1. Monosaccharide- derived sugar alcohols.
2. Disaccharide -derived sugar alcohols.
3. Polysaccharide-derived sugar alcohols mixture.

Group 1: monosaccharide - derived sugar alcohols.

Sorbitol

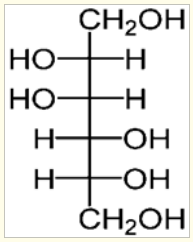


(2S, 3R, 4R, 5R)-Hexane-1, 2, 3, 4, 5, 6-hexol

Figure 1: *Sorbitol.*

Sorbitol also known by the name D-glucitol, is a six carbon sugar alcohol $C_6H_{14}O_6$ as shown in figure 1. It is naturally widely presents in fruits such as apples, grapes, plums, peaches, and cherries. Also presents in algae, and seaweeds. Because of its extraction from fruits or seaweeds are not economically feasible, it is produced by the reduction of D-glucose or D-fructose using high pressure hydrogenation [1]. Sorbitol is about 60% as sweet as the same amount of sugar sucrose. Sorbitol resist fermentation to acids by microorganisms in the mouth and therefore it does not contribute to the incidence of dental caries. Its sweetening properties allow it to be used as sugar substitute as low calorie sweetener in foods products [2] such as frozen desserts, sugar- free chewing gum, and drinks. In medicine it is used as a sweetening agent in medicinal syrups and suspensions, such as cough syrups. Also, it is used as a laxative to relieve constipation and as a diuretic to induce urination. In cosmetic products it is used as thickener and moisturizer.

Mannitol



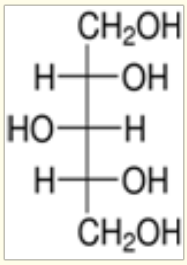
(2R, 3R, 4R, 5R)-Hexane-1, 2, 3, 4, 5, 6-hexol

Figure 2: *Mannitol.*

Mannitol also known by the name mannite or manna sugar is a six carbon sugar alcohol $C_6H_{14}O_6$ as shown in figure 2. It is naturally present in all plants and seaweeds. Mannitol concentration in these natural products can range from 20% in seaweed to 90% in plants. Mannitol is extracted from these natural products utilizing solvents or super critical fluids and generally resulting in the yield of about 18% from these original natural products. It can be also produced via the hydrogenation of the sugar mannose into mannitol [3]. Mannitol has sweet taste as the same amount of sugar sucrose and commonly used in foods and medicines [1]. In foods mannitol has lower glycemic index than sucrose and therefore used as a sweetener for people with diabetes. It has lower solubility than other sugar alcohols, however when mannitol is completely dissolved it induce a strong cooling effect. Mannitol is a very useful as a coating for hard candies, dried fruits, and Chewing gums due to its lower hygroscopic property comparing to other sugar alcohols. Mannitol is recognized by" the World Health Organization's list of essential medicines for basic health systems". It acts as an osmotic laxative in oral doses larger than 20g, and is also,

used for medical treatments such as certain cases of kidney failure with low urine output, decreasing pressure in the eyes, elimination of certain toxins, and to treat fluid buildup. In addition, researchers from Tel Aviv University demonstrated in their research experiments that mannitol could be a new approach for treating Parkinson's disease (PD).

Xylitol

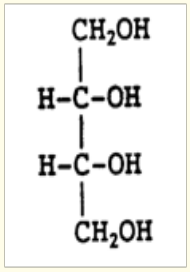


(2R, 3r, 4S)-Pentane-1, 2, 3, 4, 5-pentol

Figure 3: *Xylitol.*

Xylitol is a five carbon sugar alcohol $C_5H_{12}O_5$ as shown in figure 3. It is naturally present in most plant material, including many fruits. It is widely used as a sugar substitute and in "sugar-free" chewing gums, mints, candies, and other oral care products to prevent tooth decay and dry mouth. In medicine xylitol is used as a sugar substitute for people with diabetes. It has sweet taste but, unlike sugar sucrose, it is non fermentable by oral microflora into acids that cause tooth decay [8], Xylitol is also inhibit the growth of some bacteria that cause ear infections. In human digestive system, xylitol is poorly absorbed and acts as a dietary soluble fiber to maintain certain aspects of gut function. The bacteria in large intestine ferment xylitol into low calories short fatty acids that are absorbed by the small intestine into blood circulation as a source of energy in the metabolic pathway. Xylitol is produced by hydrogenation of the five carbon aldehyde sugar xylose (wood sugar) into primary alcohol. Another method for xylitol production is by microbial fermentation of the sugar xylose. Common yeasts for the production of high yield of xylitol by fermentation are *Candida tropicalis* and *Candida quilliemondii*. Xylitol is categorized by FDA (US Food and Drug Administration) as a food additive in sweetened products with the claim that do not promote dental cavities.

Erythritol



(2R, 3S)-Butane-1, 2, 3, 4-tetraol

Figure 4: Erythritol.

Erythritol is a four carbon sugar alcohol $C_4H_{10}O_4$ as shown in figure 4. It is present naturally in some fruits such as pears, melon, grapes and fermented foods such as wine, and cheeses. It has been approved for use as food additive through much of the world. Erythritol is produced by microbial fermentation [4,6] of sugar glucose using the osmophillic yeast such as *Moilliella pollinis* and *Trula coralline*. Mutants of these yeasts are capable to produce up to 20% erythritol yield and over 49% conversion rate of glucose into erythritol. It is a zero calorie sweetener with 60-70% sweetness comparing to the same amount of sugar sucrose, and it does not affect blood glucose [5]. Erythritol is non fermentable sweetener and does not contribute to tooth decay [7]. It does not have laxative property comparing to

other sugar alcohols because in human digestive tract [8]. It is completely absorbed from small intestine into the blood circulation and then secreted in the urine [9]. It is widely used as sweeteners in foods, confectionary [10,11] and beverages to enhance sweetness of other high intense zero calorie sweeteners such as stevia to mask the after taste property of the sweetener stevia. In pharmaceutical products it is widely used as flavoring agents, and excipients in medical tablets to enhance medicine taste. It is also widely used as preservative to inhibit bacteria in cosmetic products.

Group 2: Disaccharide - Derived Sugar Alcohols

Isomalt

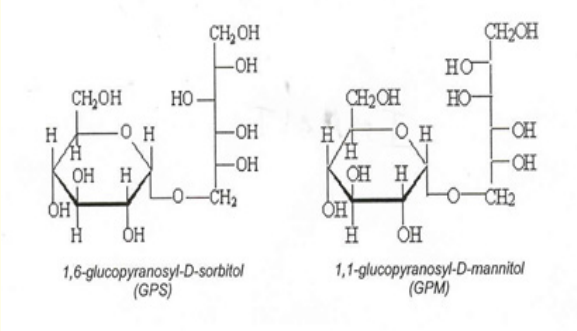


Figure 5: *Isomalt*

Isomalt is belonging to disaccharide sugar alcohols $C_{12}H_{24}O_{11}$, and it is an equimolar mixture of two chemical structures 1, 6 glucopyranosyl-D-sorbitol and 1, 1glucopyranosyl-D-mannitol as shown in figure 5. It is used primarily for its excellent taste of sugar-like bulk sweetener [12] and it has a small impact on blood sugar and does not promote tooth decay [13]. Isomalt like all polyols, it is a low digestible sugar alcohol which is partially digested in the small intestine and the non-digested portion is metabolized by bacteria in the colon [14]. It increase bowel movement like dietary fiber but carries a risk of gastric distress including flatulence and diarrhea when consumed at large quantities. Therefore, it is advised not to be consumed more than 50 g/day for adult and 25g/day for children.

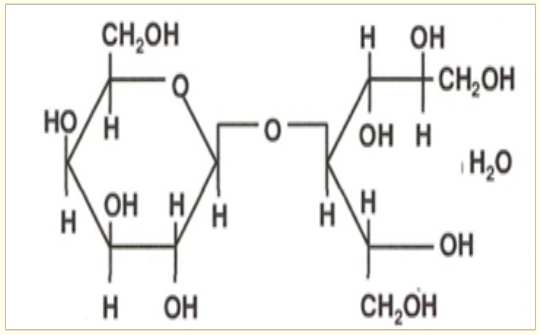
Isomalt is manufactured from sucrose in two steps process The first step is an enzymatic process using the enzyme converts to rearrange the linkage between glucose and fructose units in sucrose chemical structure from *alpha* 1, 2 glyosidic bond into 1, 6, or 1, 1glyosidic bond resulting in the formation of the intermediate chemical structure isomaltulose which is also known by the name platinose. The second process is hydrogenation process at 100^0C in the presence of catalyst for the hydrogenation of fructose unit in this intermediate isomaltulose and the formation of .the two chemical structures of isomalt. (1, 6 glucopyranosyl D-sorbitol and 1, 1 glycopyranosyl D-mannitol).

Because Isomalt can be heated without losing its sweetness it is widely used for the production of sugar -free products that are subject to high temperature such as hard-boiled candy, and baked goods. It has 45 - 65% sweetness comparing to the same amount of sugar sucrose, and it is often used in combination with sucralose for its synergistic sweetening power effects with other zero calorie sweeteners.

Lactitol

Lactitol is belong to disaccharide sugar alcohols $C_{12}H_24O_{11}$, as shown in figure 5 composed of Beta 1, 2 glyosidic bond between galactose and sorbitol (glucitol). It is a reduced calorie sweetener with a sweetness of about 40% comparing to the same amount of sugar sucrose. It is produced by hydrogenation of the disaccharide lactose in whey [15]. Similar to other sugar alcohols it has a negligible effect on blood sugar levels and can be used in diabetic and diet foods. It is used as a sweetener and texturizer in sugar-free foods, such as ice cream, chocolate, candies, baked goods, chewing gum, and infant formula. It is has applications in medicine especially used in medicinal tablets

and as an osmotically acting laxative. In human digestive tractonly about 2% of ingested lactitol is digested in small intestine to glucose and sorbitol, and absorbed into the blood circulation, the undigested portion of lactitol is passed into large intestine where it is fermented by colon microflora and converted into gas, short-chain fatty acids and lactic acid [16].

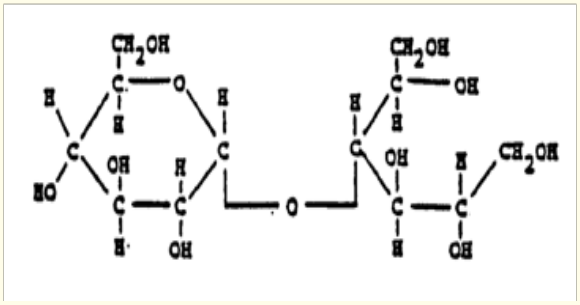


4-O-α-D-Galactopyranosyl-D-glucitol

Figure 6: *Lactitol.*

Unlike other sugar alcohols with the exception of erythritol, lactitol cause scramping, flatulence and diarrhea for some consumers. Those with health conditions should consult their physician or dietician prior to the consumption of products containing lactitol. In European Union lactitol is labeled on food products as E966.

Maltitol



4-O-α-D-Glucopyranosyl-D-glucitol

Figure 7: *Maltitol.*

Maltitol is belong to disaccharide sugar alcohols $C_{12}H_{24}O_{11}$, as shown in figure (6) composed of *alpha* 1,4 glyosidic bond between glucose and sorbitol (glucitol). It is a reduced calorie sweetener with sweetness about 80% compare to the same amount of sugar sucrose. It is produced by hydrogenation of the disaccharide maltose obtained from starch hydrolysis [17]. It exhibits negligible cooling effects in comparison to other sugar alcohols, and its high sweetness power allows it to be used without mixing with other sweeteners. Maltitol is used in foods, particularly sugar-free hard candy, chewing gums. Chocolates, baked goods, and ice cream. In pharmaceutical industry maltitol is used as an excipient and as low calorie sweetening agent for oral medicines. Its similarity in taste to sugar sucrose allow it to be used in medicinal syrups with the advantage that it does not crystallized comparing to sugar sucrose (crystallization cause bottle cap to stick). Maltitol is not metabolized by oral bacteria, so it does not promote tooth decay and because of its less absorption in human digestive tract by the small intestine than sugar sucrose [14,18]. It is more suitable for diabetes than sucrose. Its only disadvantage that its consumption at large quantities exceed 100 grams per day could have laxative effect.

Group 3: Polysaccharide Derived Sugar Alcohols

Hydrogenated starch hydrolysates (HSH)

Hydrogenated starch hydrolysates (HSH) are mixtures of several sugar alcohols such as sorbitol, maltitol, and other higher-order sugar alcohols such as Maltotriitol. They are a sweetener providing 40- 90% sweetness compare to the same amount of sugar sucrose. Hydrogenated starch hydrolysates are produced by the hydrogenation of partial hydrolyzed starch from corn, potato, or wheat. They are similar to sorbitol if the starch is completely hydrolyzed into single glucose units before hydrogenation process. Hydrogenated starch hydrolysates are used commercially in foods and medicines as other common sugar alcohols. They are often used as a sweetener and as humectant. Hydrogenated starch hydrolysates can be blended with other natural and artificial sweeteners, and can be used to add bulk, body, texture, and viscosity to food products [19]. Also, they can be used to protect biological and food products against damage from freezing and drying.

Similar to other sugar alcohols hydrogenated starch hydrolysates are non-fermentable by oral bacteria and are used to formulate sugarless products that do not promote dental caries. In human digestive tract hydrogenates starch hydrolysates are adsorbed slowly from small intestine into blood circulation, thus have a reduced glycemic potential relative to the natural sugar glucose or sucrose [20]. However Hydrogenated starch hydrolysates are also have a laxative effect when consumes in large amounts.

Discussion

Sugar alcohols or polyols have been used in diabetic foods for many years. They are carbohydrates with a chemical structure that partially resemble to sugar and partially resemble to primary alcohol, but they do not contain alcohol as alcoholic beverages. Sugar alcohols can be classified by chemical structure into three groups: monosaccharides-derived (e.g. sorbitol, mannitol, xylitol, and erythritol), disaccharides-derived (e.g. isomalt, lactitol, and maltitol), and polysaccharide-derived mixture (e.g. hydrogenated starch hydrolysates mixtures).

Sugar alcohols occur naturally in wide variety of fruits, vegetables, and seaweeds but are commercially produced from other carbohydrates, such as glucose, mannose, xylose, lactose, maltose and starch. They have a long history of use in wide variety in food products like candy, gum, ice cream, baked goods, and fruit spreads. In medicines they have applications like cough syrups, and medicinal tablets; in oral hygiene products they have applications like toothpaste, mouthwashes and breath mints; plus they have some applications in cosmetics. From all sugar alcohols, sorbitol is the most used one with higher market chare comparing to others due to its lowest manufacturing cost from glucose or fructose.

All sugar alcohols are regulated by FDA (Food and Drug Administration) in United States and by other worldwide similar organizations. They are Generally Recognized as Safe (GRAS) and approved by all worldwide authorities for the application in foods as food additives and in other products such as medicine and cosmetics.

Sugar alcohols playing important roles in health, they are partially absorbed from small intestine into blood circulation with a minimal effect on blood glucose and insulin.

Dental caries is the major problem in regards to excessive natural sugar consumption especially by children, but with sugar alcohols as sweeteners this is not a problem, since the bacteria in the mouth don't ferment sugar alcohols into acids. Due to non-fermentable properties of sugar alcohols manufacturers of chewing gums and sugar less candies and breath mints incorporate sugar alcohols as sweetener such as xylitol in their products. The sugar alcohol xylitol are more desirable in these products because it has a similar sweetness taste compare to the same amount of sugar sucrose as shown in table (1).

Some of sugar alcohols are not absorbed into blood circulation and direct pass through the small intestine into large intestine where are fermented by the bacteria in the large intestine into abdominal gas causing discomfort and diarrhea for some individuals. Given the increasing availability of sugar alcohols sweetened foods and due to the expanded number of low calories food products in the market the

total daily intake per day of each sugar alcohols are considered to prevent GI disturbance or laxative effects. In European Union products containing sugar alcohols must be bear a statement" "*excess consumption may have laxative effect*".

As shown in Table (1) Sugar alcohol's caloric value, and sweeteners level comparing to the same amount of sugar sucrose in foods are listed and showed the following

The Sugar Alcohols			
Type	Calories per Gram	Approximate Sweetness (Sucrose = 100%)	Typical Food Applications
Sorbitol	2.6	50-70%	Sugar free candies, chewing gums, frozen desserts and baked goods
Xylitol	2.4	100%	Chewing gum, gum drops and hard candy, pharmaceuticals and oral health products, such as throat lozenges, cough syrups, children's chewable multi vitamins, tooth pastes and mouth washes, used in foods for special dietary purposes
Maltitol	2.1	75%	Hard candies, chewing gum, chocolates, baked goods and ice creams
Isomalt	2.0	45-65%	Candies, toffee, lollipops, fudge, wafers, cough drops, throat lozenges
Lactitol	2.0	30-40%	Chocolates, some baked goods (cookies and cakes), hard and soft candy and frozen dairy desserts
Mannitol	1.6	50-70%	Dusting powder for chewing gums, ingredient in chocolate flavored coating agents for ice cream and confections
Erythritol	0-0.2*	60-80%	Bulk sweetener in low calorie foods
Hydrogenated Starch Hydrolysates	3	25-50%	Bulk sweetener in low calorie foods, provide sweetness, texture and bulk to a variety of sugarless products

Table 1: *Calories, sweetness and food applications for common sugar alcohols.*

The highest calorie in all sugar alcohols are hydrogenated starch hydrolysates (3.0 calorie per gram) and the lowest one is erythritol (0.2 calorie per gram).

In term of sweetness comparing to the same amount of sugar sucrose, demonstrated that the highest sweetness in all sugar alcohols is xylitol (100%) and the lowest one are hydrogenated starch hydrolysates (25-50% depend on the type of application).

Conclusion

For decades sugar alcohols have been used as alternative to sugar. They look and taste like sugar but with lower calories and many studies show that they lead to health improvements and fewer negative effects.

Because sugar alcohols have similar chemical structure as sugar, they are able to activate the sweet taste receptors in the tong. This chemical property allows the application of sugar alcohols as alternative sweetener to high glycemic index sugars without negative effect on products quality and taste. The glycemic index is a measure of how quickly foods raise blood sugar level, and consuming food that is high in glycemic index is associate with obesity and numeric metabolic health problems. Sugar alcohols have a negligible effect on blood sugar level and for people with metabolic syndrome, pre-diabetes or diabetes; sugar alcohol can be considered as excellent alternative to sugar.

Bibliography

1. Friedrich Reiff., *et al.* "Sorbitol, process for its preparation, and use there of US". 4605794A (1986).
2. Kearsley MW and Deis RC. "Sorbitol and Mannitol, In Sweeteners and Sugar Alternatives in Food Technology". *Amex: Oxford* (2006): 249-261.
3. Song SH and Vieille C. "Recent advances in the biological production of mannitol". *Applied Microbiology and Biotechnology* 84.1 (2006): 55-62.
4. Aoki M., *et al.* "Microbial transformation of sucrose and glucose to erythritol". *Biotechnology Letters* 15 (1993): 383-388.
5. Noda K., *et al.* "Serum glucose and insulin levels and erythritol balance after oral administration of erythritol in healthy subjects". *European Journal of Clinical Nutrition* 48.4 (1994): 286-292.
6. Hajny GJ., *et al.* "Erythritol production by yeast like fungus". *Applied Microbiology* 12(1964): 240-244.
7. Arrigoni E., *et al.* "Human gut microbiota does not ferment erythritol". *British Journal of Nutrition* 94.5 (2005): 643-646.
8. Storey D., *et al.* "Gastrointestinal tolerance of erythritol and xylitol ingested in a liquid". *European Journal of Clinical Nutrition* 61.3 (2007): 349-354.
9. Bunro IC., *et al.* "Erythritol: an interpretive summary of biochemical, metabolic, toxicological and clinical data". *Food and Chemical Toxicology* 36.12 (1998): 1139-1174.
10. Kawanabe J., *et al.* "Non carcinogenicity of erythritol as a substrate". *Caries Research* 26.5 (1992): 358-362.
11. Goossens J and Roper H. "Erythritol: a new sweetener". *Confectionery Production (United Kingdom)* 24 (1994): 182-188.
12. Bolhuis GK., *et al.* "Eur Compaction properties of isomalt". *Journal of Pharmaceutics and Biopharmaceutics* 72.3 (2009): 621-625.
13. Featherstone JDB. "Effects of isomalt sweetener on the caries process: are view". *The Journal of Clinical Dentistry* 5 (1990): 82-85.
14. Langkilde AM., *et al.* "Digestion and absorption of sorbitol, maltitol and isomalt from the small bowel. A study in ileostomy subjects". *European Journal of Clinical Nutrition* 48 (1995): 768-775.
15. Lonny Lee Wilson. "Process for the manufacture of a lactitol syrup". US Patent 6090429A (2000).
16. Maydeo A. "Lactitol or lactulose in the treatment of chronic constipation: result of a systematic. *Journal Of Indian Medical Association* 108.11 (2010): 789-792.
17. Hirao M. "Process for producing maltitol US". 3708396 A (973).
18. A Ruskoné-Fourmestraux., e*t al.* "A digestive tolerance study of maltitol after occasional and regular consumption in healthy humans". *European Journal of Clinical Nutrition* 57 (2003): 26-30.
19. Francoise Verwaerde., *et al.* "Non-cariogenic hydrogenated starch hydrolysate for confectionery and process for preparing this hydrolysate US". 4279931A (1981).
20. Modderman JP. "Safety assessment of hydrogenated starch hydrolysates". *Regulatory Toxicology and Pharmacology* 18.1 (1993): 80-114.

Volume 4 Issue 2 June 2016