Sugar Alcohol: A Comparison of Xylitol and Sorbitol in Food Application

Abhirama Radya Asasta¹, Dechen Wangmo Armando², Janice Clarisa Tissadharma³, Kimberly Alecia Theo⁴, Natasya Nobelta⁵

¹,²Food Technology, I3L, Jakarta, Indonesia
³,⁴,⁵Food Science and Nutrition, I3L, Jakarta, Indonesia

Email untuk Korespondensi: abhirama.asasta@student.i3l.ac.id dechen.armando@student.i3l.ac.id janice.tissadharma@student.i3l.ac.id Kimberly.theo@student.i3l.ac.id Natasya.nobelta@student.i3l.ac.id

ABSTRAK


Kata kunci:
Alcohol sugar xylitol sorbitol food

Keywords:
sugar alcohol xylitol sorbitol food
**INTRODUCTION**

Sugar has been regarded as one of the essential components required on a daily basis as a source of energy (Singh et al., 2020). However, the consumption of sugar has been a significant threat to health given that it raises the risk of obesity and chronic non-communicable diseases such as diabetes, cardiovascular disease, and respiratory illnesses (World Health Organization, 2015). According to a poll in Portuguese on people's understanding of sugar sources and intake, 1010 people, one-fourth of the population exceeded the WHO-recommended daily limit of consuming sugar (Prada et al., 2020). Diabetes and obesity epidemics prompted changes in societal eating habits and food product knowledge (Grembecka, 2015). The food industry has produced a number of energy-reduced food products using sugar alcohols as sweeteners in response to consumer demand.

Modern culinary products nearly universally use artificial sweeteners as a substitute for table sugar which has significant calories (Grembecka, 2015). The rising incidences of obesity and diabetes fueled consumer demand and the expansion of the artificial sweetener market (Awuchi & Echeta, 2019). Sweeteners can be classified into two categories: nutritive and artificial. Though it is known to have no calories or blood sugar effects, is beneficial in lowering blood glucose response, and is digestible without insulin control, this is not always the case. Additionally, sugar alcohols are used in food applications to add texture, retain moisture, and prevent food from browning (Grembecka, 2015). However, some drawbacks must be taken into account, such as side effects of bloating, flatulence, and diarrhea when consumed in excessive amounts (Godswill, 2017). Due to the aforementioned issue, more information about sugar alcohols was required, and assessed their uses in the food system.

This paper focuses on sugar alcohol mainly xylitol and sorbitol. The role of sugar alcohol as a sweetener was initially examined. Both the introduction of xylitol and sorbitol and its production procedure will be covered in this paper. The method for production, its use in food systems, along with its chemical and nutritional worth. Furthermore, the benefits and drawbacks of both sugar alcohols as well as the precautions associated with consumption have been addressed.

**METHOD**

The research used qualitative approach with the content analysis method. The researchers gathered data from different sources, mainly from books and scientific journals, then extracted and categorized them into respective sub-sections as displayed in the next section. The researchers analyzed the data using Miles and Huberman (2014) technique.

**RESULT AND DISCUSSION**

**Sugar alcohol as sweeteners**

Sugar alcohols are a subclass of polyols, which are chemical molecules that are commonly formed from sugars (Godswill, 2017). Generally, sugar alcohols are referred to as polyhydric alcohols, polyalcohols, alditols, or glycitols. A sugar alcohol is neither a sugary substance nor an alcoholic potion. Sorbitol, mannitol, xylitol, isomalt, and hydrogenated starch hydrolysates are examples of sugar alcohols that are frequently included in food products and classified as nutritive sweeteners based on European Union Law (EU law). They are commonly utilized as thickeners and sweeteners (Awuchi & Echeta, 2019). Furthermore, due to the sweetness of sugar alcohols are often lower than that of monosaccharides, they are often employed in place of sugar and are referred to as bulk sweeteners (Grembecka, 2015). To get the right taste and sweetness, they are frequently combined with other sweeteners. Similar to carbs, they are also in charge of the texture of the product, its preservation, filling, retaining moisture, and the cooling feeling in the mouth.

**Xylitol**

Xylitol is a five-carbon polyol (sugar alcohol), with a low-calorie and crystalline structure (Martins et al., 2022). The presence of five hydroxyl groups allows xylitol to have a great affinity for water, which allows it to be soluble in solutions (Arcaño et al., 2020). The high hygroscopicity also causes xylitol to absorb water from food (Sun et al., 2013). Xylitol is normally produced in fruits and vegetables, but it can be found in hardwood trees, such as plant husks and stalks. Moreover, humans and animals are able to create a small
amount of xylitol during glucose metabolism, with an average of 5 to 15 grams of xylitol produced per day (Umai et al., 2022).

It has various applications in the food and pharmaceutical industry. Xylitol has a similar flavor and sweetness as sucrose, and it is recommended to be consumed by diabetic patients since the metabolism does not require insulin. It has also been proven that xylitol is able to prevent tooth decay, thus it has been incorporated into some healthcare products such as toothpaste, and mouthwash (Rafiqul & Sakinah, 2013). Therefore, xylitol can be regarded as a dental friendly non-fermentable sugar alcohol.

Sorbitol

Sorbitol belongs to a category of carbohydrates known as sugar alcohols or polyols, which are soluble in water and can be found naturally in numerous fruits and vegetables. Additionally, sorbitol is manufactured from glucose for its application in processed foods and beverages to impart sweetness, enhance texture, and maintain moisture content (Awuchi & Echeta, 2019). Similar to the majority of sugar alcohols, sorbitol doesn’t possess the same level of sweetness as regular sugar nor the same calorie density. Sorbitol’s sweetness is approximately 60% sugar, and it contains around 35% fewer calories per gram (2.6 calories in sorbitol versus 4 calories in sugar) (Galán et al., 2021).

Production of Xylitol

Xylitol can be produced by two processes: chemically with a catalyst or bio-technologically with yeast, fungi, or bacteria. Xylitol can also be produced chemically by catalytic hydrogenation of xylose, with the presence of nickel or aluminum catalyst under extreme temperature and pressure (180 °C; 50 atm) (Carneiro et al., 2019). Xylitol is frequently found in mixtures containing xylitol, xylose, and arabinose. Purification is therefore needed to increase its value, which can be accomplished using crystallization, adsorption, or membrane technology (Faneer et al., 2016). Xylitol can also be produced from xylans, which is hemicellulose derived from agricultural waste. Xylan is first hydrolyzed into xylose, which can be done through acidic or enzymatic hydrolysis. Xylose is then hydrogenated with the help of a Raney nickel catalyst. It is then autoclaved at a temperature of 135°C and pressure of 40 atm for 2.5 hours (Arifan & Nuswantari, 2020).

Other than using metal catalysts, industries normally use nanofiltration membranes as it’s considered economically effective when compared to other techniques (e.g. evaporation). Xylitol is produced from D-xylose through the fermentation process which will then undergo a separation process to separate from the other components of the fermentation broth (e.g., metabolic products, residual chemicals, biomass cells, and mineral salts) prior to being refined as xylitol crystals. As a result, several separation techniques are required to get high-purity xylitol. Membrane separation is a viable downstream processing approach(11). Membrane technology plays an important role in purification and separation for various applications due to its simple and flexible operation, it’s also compatible with various applications (Faneer et al., 2016).

Xylitol can also be produced through microbial and enzymatic methods. The microbial process utilizes bacteria, yeast, or fungi to produce xylitol from xylose or hemicellulose hydrolyzate (Rafiqul & Sakinah, 2013). Xylitol is produced as an intermediate product in the metabolic pathway of xylose. In yeast and fungi, D-xylose is reduced into xylose by xylose reductase. The produced xylitol is then secreted out of the cell, or it can be further oxidized by xylitol dehydrogenase to form D-xylulose (Azizah, 2019). Similarly, several bacteria strains such as Enterobacter and Corynebacterium species also have xylitol reductase which can produce xylitol (Umai et al., 2022).

There are several benefits of using microbial and enzymatic methods to produce xylitol. This method is cost-effective and requires low energy as the process relies on microorganisms. Moreover, it does not cause environmental problems as it does not produce any metal waste (Mardawati et al., 2018).

Production of Sorbitol

Sorbitol production typically utilizes cellulose in the presence of noble metals and transition metal-based catalysts. However, utilizing glucose to produce sorbitol could be another alternative. At a large scale production, sorbitol production is produced through glucose hydrogenation due to being the most cost-efficient. The mechanism consists of the reduction of carbonyl groups of saccharide under hydrogen pressure with the presence of a solid metal catalyst (Ni, Pd, Pt, or Ru) (García et al., 2019).

Similarly, sorbitol production is also possible with the use of bacteria such as Lactobacillus casei, Lactobacillus plantarum, Synechocystis sp., and Zymomonas mobilis (Rice et al., 2020). The most popular bacteria is Z. mobilis due to its ideal biocatalyst properties such as high osmolarity and ethanol tolerance, requires low oxygen for fermentation, high utilization rate, and thermotolerant strains (Braga et al., 2021). The process involved a mixture of glucose and fructose as the medium and an enzyme produced by Z. mobilis called glucose-fructose oxidoreductase (GFOR), which has been found to produce a high yield of sorbitol (Folle et al., 2018).
According to Sootsuwan et al. (2013), the mechanism began in the periplasm, the space between the inner and outer membrane, where glucose enters the periplasmic space to be converted into gluconolactone which then leaves the enzyme and fructose is reduced to sorbitol in a one-step reaction. The sorbitol acts as protection against osmotic stress caused by the concentrated sugar medium. After sufficient amounts of sorbitol are produced, a purification process using multi-effect evaporators, where the first chamber is evaporated into steam which then be used as the heating medium for the next chamber to increase temperature based on solubility, is used to condensate sorbitol (Godswill, 2017). Sorbitol has a different solubility from water which enables a separation without impurities (Galán et al., 2021). However, this bacteria is ethanologenic, which produces high amounts of ethanol and can limit the production of sorbitol, therefore, methods such as strain engineering, increasing the substrate concentration, and turning the cells into a permeabilized or immobilized state have been applied for maximum yield of sorbitol (He et al., 2014).

Chamnipa et al. (2022) added that the raw materials such as glucose-fructose mixture are expensive which contributed to high production costs, the author has found a cheaper alternative but fewer yield using lignocellulosic biomass of sugarcane bagasse and cassava pulp obtained from rarely used industrial byproducts. This opens the possibility of an economical method for industrial production to produce highly demanded sorbitol.

**Chemical Composition of Xylitol**

With asymmetric carbon atoms, the molecule of xylitol is symmetrical, preventing it from being chiral. All five of the molecule's carbon atoms are bound to an OH group; the xylitol molecule lacks reducing groups (Mäkinen, 2014). Due to the lack of free aldehyde/ketonic groups (reducing properties), xylitol does not undergo the browning reaction (Ahuja et al., 2020). The tridentate ligand (H-C-OH) found in the structure of xylitol can rearrange with polyvalent cations like Ca\(^{2+}\). Ca\(^{2+}\) can pass through and through the gut wall barrier thanks to this interaction (Godswill, 2017).

**Chemical Composition of Sorbitol**

Since hexane (C\(_6\)H\(_{14}\)) and sorbitol (C\(_6\)H\(_{14}\)O\(_6\)) have similar skeletal structures, they can be directly changed to one another through deoxygenation (Gunawan et al., 2021). Sorbitol can be used as a raw material to create compounds that are often obtained from fossil fuels, such as ethylene glycol (EG), propylene glycol (PG), glycerol, lactic acid, and isosorbide and alkanes (Yang et al., 2023).

**Comparison of Xylitol and Sorbitol as Sweeteners**

<table>
<thead>
<tr>
<th>Compound</th>
<th>Relative Sweetness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polyol(^a)</td>
<td></td>
</tr>
<tr>
<td>Xylitol</td>
<td>80-100</td>
</tr>
<tr>
<td>Sorbitol</td>
<td>50-60</td>
</tr>
<tr>
<td>Mannitol</td>
<td>50-60</td>
</tr>
<tr>
<td>Maltitol</td>
<td>80-90</td>
</tr>
<tr>
<td>Lactitol</td>
<td>30-40</td>
</tr>
<tr>
<td>Isomalt</td>
<td>40-50</td>
</tr>
<tr>
<td>Erythritol</td>
<td>60-70</td>
</tr>
<tr>
<td>Sucrose(^a)</td>
<td>100</td>
</tr>
</tbody>
</table>

\(^a\) = 10% in H\(_2\)O at 20°C

Based on Rapaille et al. (2016) data on sweetness values in different sugar alcohols, it could be determined that xylitol has a higher relative sweetness to sucrose than sorbitol. The reason sugar alcohol has different relative sweetness is due to the activation of G-protein sweet receptors which reside in the tongue's taste buds. The G protein-coupled receptor T1R2/T1R3, which regulates sweetness. Xylitol has a sweeter taste than sorbitol because of its substantially increased binding affinity for the T1R2 monomer (Mahalapbutr et al., 2019).
Sugar Alcohol in Food Application

**Xylitol**

1) Chewing gums: Xylitol has been incorporated into lots of food products such as chewing gums due to its negative heat properties (cooling effect) (Mäkinen, 2014). When the xylitol chewing gum is chewed for a long time, it stimulates the production of saliva and washes off the debris. Oral microorganisms are unable to metabolize xylitol, thus it inhibits the pathway of caries-producing microorganisms (Nassar, 2017). Routine consumption of xylitol chewing gums has been correlated with a decreased amount of dental plaque. Furthermore, the plaque of xylitol consumers is less adhesive, since xylitol is also able to lower the amount of Streptococcus mutans, a bacteria that triggers the formation of dental plaque (Söderling & Pienihäkkinen, 2021).

2) Bakery products: Xylitol can also be incorporated into bakery products as sweeteners as xylitol is a good sugar replacement for diabetics (Prada et al., 2020). However, the addition of xylitol affects the texture and sensorial properties of bread. Research conducted by Sun et al. (2013) shows that the addition of xylitol with a preferred range of 0 - 5% gives a finer crust color, while the bread with a 15 - 20% addition of xylitol resulted in a finer color, too much xylitol prevents the formation of the gluten network. When more xylitol is added, the bread volume decreases as xylitol reduces expansion during fermentation and baking. Yeast is unable to utilize xylitol and it affects the fermentation process, thus reducing the expansion.

**Sorbitol**

1) Bakery products: Sorbitol can be added to bakery products as sugar replacements, so the product can be safely consumed by diabetics. It can be incorporated into products such as bread and cakes. In bread, hexabasic alcohol sorbitol shows great moisturizing and emulsifying capabilities (Yang et al., 2023). Other than being able to preserve moisture, it is also able to decrease the water activity in bread. It is also able to improve the gluten’s water retention activity, which increases the softness of bread (Zhou et al., 2016). It is also used as a humectant to extend the shelf life of baked products. In other products such as cake, partial substitution of sucrose by sorbitol can improve the stability of the food (Caballero et al., 2016).

2) Chewing gums: In chewing gums, sorbitol is also commonly added as a sweetening agent, saliva stimulation, and reduction of plaque acid on teeth similar to xylitol. Chewing gums increases saliva flow through stimulation of gustatory or taste from the sweetening agent and mechanical or chewing to process the food (Pedersen et al., 2018). According to Sri et al. (2022), Sorbitol has a one-third of effectiveness compared to xylitol but the production cost is much cheaper, whereas xylitol requires high amounts of usage to achieve therapeutic effects which affects the long-term costs. Unlike xylitol which cannot be fermented by oral microorganisms, sorbitol can still be fermented by Streptococcus mutans and Lactobacilli but has a slower metabolism rate than sucrose (Oza et al., 2018). Thus, sorbitol is used as an additional sugar alcohol with xylitol in chewing gums to cut costs (Keukenmeester et al., 2014).

3) Sugar-free chocolates: The role of sugar, commonly sucrose, in chocolates is to increase the volume or bulkiness, create desirable texture, and give characteristic sweetness. Sugar alcohols including sorbitol and xylitol are known as “bulk sweeteners” to substitute sucrose and produce similar results (Nur et al., 2021). Additionally, sugar alcohols in chocolates result in low calories and glycemic index properties due to the slow absorption rate of sugar alcohols in the intestine (Greimbecka, 2015). Selvasekaran and Chidambaram (2021) wrote that in terms of sweetness to sucrose, xylitol has equal sweetness while sorbitol only has 60% of sweetness. However, sorbitol is more commonly used as a bulking agent, thanks to the particle size distribution to accommodate more space inside the chocolate and good moisture retention, which provides the same or better bulk density and texture and less expensive production costs than xylitol (Aidoo et al., 2013). At high concentrations, both may produce undesirable deformation properties due to its hygroscopic behavior and may also create a cooling sensation that is unwanted to some consumers (Homayouni Rad & Rasouli Pirouzian, 2020).

Advantages of Sugar Alcohol

Polyols, on the other hand, are excellent for diabetics because they prevent a quick glycemic or insulinemic response (Prada et al., 2020). In parenteral nutrition, sorbitol and xylitol are frequently used to give a more manageable carbohydrate energy supply than glucose or fructose.

**Xylitol**

Due to its low caloric content, insulin-independent metabolism, prebiotic nature, anabolic effects, and safety, xylitol has a wide range of potential health advantages. The deterioration of teeth is not facilitated by sugar alcohols (Godswill, 2017). Although less so than sucrose, the use of sugar alcohols may have an impact
on blood sugar levels. Xylitol has much lower blood glucose and insulin responses (Rehman et al., 2016). It has an energy value of 2.4 kcal/g. The sweetness intensity of this sugar alcohol is only slightly less than that of sucrose. Hence, it is utilized as a food additive in confectionery, bakery, beverages, dairy goods, as well as in the pharmaceutical business. Additionally, the production of a cold aftertaste is another benefit of employing xylitol as a sweetener in chewing gum, soft beverages, cooled desserts (chocolates, ice creams, pudding), confectionery, and jams (Ahuja et al., 2020).

**Sorbitol**

Sorbitol provides calories through its carbohydrate content. It has a low glycemic index, thus it is absorbed gradually and only partially in the small intestine, which increases the blood glucose slowly (Grembecka, 2015). The unabsorbed sorbitol proceeds to the large intestine, where it yields fewer calories through metabolism. Consequently, when compared to an equivalent amount of sugar, sorbitol consumption leads to reduced insulin secretion, contributing to lower blood glucose levels (Rains & Jain, 2011).

Sugar alcohols, like sorbitol, have demonstrated advantages for oral health through various mechanisms, primarily due to their non-cariogenic nature, meaning they do not promote the formation of cavities (González et al., 2014). Chewing, as an action, also shields teeth from bacteria that cause cavities by stimulating saliva flow. The combination of increased saliva production, non-cariogenic qualities, and sweetness is why sugar alcohols such as sorbitol and xylitol are incorporated into sugar-free chewing gum (Nadimi et al., 2011).

**Disadvantages of Sugar Alcohol**

With the exception of erythritol, sugar alcohols may also result in bloating and diarrhea if ingested in excess (Prada et al., 2020). In order to prevent gastrointestinal discomfort, it is advised that polyol intake be limited to 40–50 g per day for adults and 30 g per day for children due to their decreased digestibility. Due to slow-pace absorption and extensive fermentation, higher doses may result in osmotic diarrhea or increased flatulence, however, tolerance levels increase with adaptation.

**Xylitol**

Compared to glucose or fructose, xylitol is not as well absorbed in the human intestine (Godswill, 2017). These properties made it unsuitable for individuals with low glucose levels. Since the conversion is gradual, xylitol functions as a low-GI supply of energy. Furthermore, in comparison to several sugar alcohols, Xylitol has a lower laxation threshold which individuals need to be aware of. The laxative threshold is the highest dosage tolerated without nausea, vomiting, or other unpleasant gastrointestinal side effects. These effects might vary for different individuals.

**Sorbitol**

One notable drawback associated with sorbitol is its capacity to induce digestive unease and a laxative response, particularly when ingested in substantial quantities. Sorbitol undergoes incomplete absorption in the small intestine, and the unabsorbed sorbitol can attract water into the intestines, resulting in symptoms such as diarrhea, abdominal bloating, and cramps (Lenhart & Chey, 2017). Excessive consumption of sorbitol, which induces a laxative response, has the potential to result in fluid depletion and dehydration (Phillip et al., 2017). Therefore, it is crucial to ensure proper hydration when consuming products that contain sorbitol.

**CONCLUSION**

Sugar alcohols are organic substances originating from sugars and belong to a category of compounds known as polyols. Despite its name, it’s important to note that sugar alcohols are not sugars, nor are they alcoholic beverages. Within the food industry, they have extensive applications as both thickeners and sweeteners. Xylitol is a good sugar replacement for diabetics while sorbitol is produced from glucose for use in processed foods and beverages with the purpose of adding sweetness, improving texture, and preserving moisture levels. There has been an increasing demand for sugar-free products, substituting common sugar (sucrose) in food to reduce the calorie and glycemic index, sugar alcohols can be the solution to these problems but have side effects such as laxative effects, may pose harder challenges in food production due to hygroscopic behavior, expensive production costs, xylitol requires more administration frequency and pellets to achieve therapeutic effects, and so on. The purpose of this research paper is to evaluate the difference in properties of commonly used sugar alcohols, sorbitol, and xylitol, and to determine which of the two are the most suited ones in food. In terms of production cost, sorbitol is preferable to xylitol because it is cheaper which allows for more application in food products compared to xylitol. However, in terms of dental considerations, xylitol has better benefits compared to sorbitol. Both sorbitol and xylitol are low in calories, however, they must be used carefully, especially in sorbitol which may result in gastrointestinal discomfort when consumed excessively.
For future recommendations, there can be modifications for sorbitol and xylitol to reduce laxative effects when consumed and to control the hygroscopic behavior for food application.

REFERENCE


Sugar Alcohol: A Comparison of Xylitol and Sorbitol in Food Application


