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Sugar alcohols: A review

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Abstract : Sugar alcohols are extensively used as sweetening agents. They sometimes possess advantages over the parent sugars in sweetness, caloric reduction and non-cariogenicity. The physical status of carbohydrates in food and confectionery affects both the properties of the product during production and the quality of the final product. Sugar alcohols, such as xylitol, mannitol, sorbitol, and erythritol are emerging food ingredients that provide similar or better sweetness/sensory properties of sucrose, but are less calorigenic. Also, sugar alcohols can be converted into commodity chemicals through chemical catalysis. Biotechnological production offers the safe and sustainable supply of sugar alcohols from renewable biomass. These compounds are usually produced by a catalytic hydrogenation of carbohydrates, but they can be also found in nature in fruits, vegetables or mushrooms as well as in human organism. Due to their properties, sugar alcohols are widely used in food, beverage, confectionery and pharmaceutical industries throughout the world. They have found use as bulk sweeteners that promote dental health and exert prebiotic effect. They are added to foods as alternative sweeteners what might be helpful in the control of calories intake. Consumption of low-calorie foods by the worldwide population has dramatically increased, as well as health concerns associated with the consequent high intake of sweeteners.

Key words: Sugar alcohols, low-calorie, Sugar-free products, sweetener.

1. Introduction

Sugar alcohols are a class of polyols in which sugar's carbonyl (aldehyde or ketone) is reduced to the corresponding primary or secondary hydroxyl group. They have characteristics similar to sugar and are used to improve the nutritional profile of food products owing to health-promoting properties such as lower caloric content, noncariogenicity, and low glycemic index and insulin response[1]. Other auspicious qualities as food additives include high enthalpies of solution and lack of reactive carbonyls. Sugar alcohols additionally find many applications in pharmaceuticals, chemicals production, oral and personal care, and animal nutrition[2].

They are found naturally in fruits and vegetables and are produced by microorganisms, serving as carbohydrate carbohydrate reserves, storage of reducing power, translocatory compounds, and osmoprotectants. Most sugar alcohols are industrially produced by the catalytic hydrogenation of sugars under high pressure and temperature. However, current chemical processes require extreme conditions and costly chromatographic purification steps, which leads to low final product yields[3]. Because of these drawbacks, biotechnological production has been actively pursued[4]. Biotechnological production based on microbial fermentation offers safer and environmentally friendly processes and economic utilization of agricultural waste residues. While traditional strategies to improve sugar alcohol production through isolating better strains and optimizing culture conditions have been diminishing, metabolic engineering to improve production of sugar alcohols have been extensively pursued to establish economic microbial production platforms[5].

Sugar alcohols (polyols or polyhydric alcohols) are low digestible carbohydrates, which are obtained by substituting and aldehyde group with a hydroxyl one[6]. As most of sugar alcohols are produced from their corresponding aldose sugars, they are also called alditols[7]. Among sugar alcohols can be listed hydrogenated monosaccharides (sorbitol, mannitol), hydrogenated disaccharides (isomalt, maltitol, lactitol) and mixtures of hydrogenated mono-diand/ or oligosaccharides (hydrogenated starch hydrolysates)[6]. Polyols are naturally present in smaller quantities in fruits as well as in certain kinds of vegetables or mushrooms, and they are also regulated as either generally recognized as safe or food additives[8]. Food additives are substances that are added intentionally to foodstuffs in order to perform certain technological functions such as to give color, to sweeten or to help in food preservation.

Sugar alcohols' sweetness is usually lower than the one of monosaccharide, and therefore, they are used volume-for- volume like sugar and are called bulk sweeteners. They are often used in combination with other sweeteners to achieve the desired level of sweetness and flavor. Similarly to carbohydrates, they are not only responsible for sweet taste, but they are also responsible for product texture, its preservation, filling, holding moisture and cooling sensation in the mouth[9].

Sugar alcohols due to lower caloric value might help consumers to reduce their similar to fiber can help normalize intestine function[10]. Sugar alcohols such as maltitol and lactitol were found to increase mineral bioavailability in human and rats[11]. The present review focuses on the role and metabolism sugar alcohols such as erythritol, isomalt, lactitol, maltitol, mannitol, sorbitol and xylitol.

2. Sugar alcohols characteristics

2.1. xylitol

Xylitol (five carbon sugar alcohol), an artificial sweetener, could be produced from second most abundant polysaccharide, xylan rich hemicellulose which on hydrolysis produces xylose. It is a sugar substitute used in dietary, food and pharmaceutical industries due to its properties like low energy content, anticariogenicity, tooth rehardening, preventive against otitis, ear and upper respiratory infections etc.[12]

D-Xylitol, a five-carbon polyol discovered by the German chemist Emil Fischer[13] has almost equal sweetness to sucrose, but with curtailed caloric content (2.4 vs. 4 cal/g for sucrose)[14]. Xylitol naturally occurs in fruits and vegetables, in very small quantity, and is also produced as a metabolic intermediate in adult human in the range of 5–15 g/day[15].

The present industrial production of xylitolis mainly from chemical route that involves hydrogenation of d-xylose using Ni-catalyst at high temperature and pressure[16]. In addition to the expensiveness of this process, high cost of pure xylose and expensive refining treatment for xylitol purification increase the overall cost of production[16]. Because of the uneco-nomical extraction of xylitol from natural sources, researchers are encouraged to explore other potential alternatives such as microbial production of xylitol involving microorganisms (e.g., yeast, bacteria, fungus, and molds), where agro-industrial waste recycling would be an added advantage[17].

In recent years, many potential lignocellulosic raw materials such as sunflower stalks[18], vegetable residues[19], bamboo[20], and napier grass[21] have been evaluated for the production of xylitol and ethanol. Recently, development of a single-step process for xylitol production from corncob xylan by expressing two xylanases encoded by atn (xylanase gene) and atl (xylosidase gene) from Aspergillus terreus Li-20 in Candida tropicalis BIT Xol-1 has been reported to produce 3.01 g/L of xylitol (with 66.9% yield) after 84-h fermentation[22].

A thermo-tolerant NADP (H)-preferring xylose pathway was constructed in Kluyveromyces marxianus for ethanol production with xylose at elevated temperatures[23].

Converting xylose into xylitol is a more economical strategy. The low efficiency of xylose fermentation is also a limitation in bioethanol production. A lot of works were tried to convert xylose into ethanol and avoid the byproduct xylitol. However, xylitol is also a very important chemical which has higher value than ethanol and is widely used as food additive[24]. Moreover, as a valuable synthetic building block, xylitol is also classified as one of the most promising chemicals among the 12 bio-based chemicals by the US Department of Energy and thereby serves as a key economic driver of the biorefinery concept[25]. To convert glucose into ethanol and xylose into xylitol may be more economical in the lignocellulosical biofuel production[26].

2.2. Erythritol

1,2,3,4-Butanetetrol, which is a chemical name of erythritol (Fig. 1), can be naturally found in small quantities in vegetables, fruits (melons, peaches), mushrooms and fermented foods such as wine, beer, sake and soy sauce[27]. It can be also found in several human tissues such as semen, lens, cerebrospinal fluid and serum[28]. Erythritol consumption from natural sources is estimated to amount from 25 mg/person/day in the USA to 106 mg/person/day in Japan[28].

2.3. Lactitol

It was discovered in 1920 by a French food chemist but not commercially used until 1980's. Lactitol is a disaccharide polyol, which is composed of sorbitol and galactose (Fig. 1). It is produced from lactose by a catalytic hydrogenation using Raney nickel as the catalyst[29]. Lactitol is metabolized by bacteria in the large intestine, where it is converted into biomass, carbon dioxide, a small amount of hydrogen and organic acids[29], which are further metabolized to give energy in the amount of 2–2.4 calories per gram.

2.4. Maltitol

Maltitol (4-O-ά-glucopyranosyl-D-sorbitol) is a disaccharide alcohol and is characterized with sweetness similar to that of sucrose (approved for 1 or 100%) and the relative sweetness of maltitol is 0.9[30].

Maltitol, also called 4-O-α-d-glucopyranosyl-d-glucitol (Fig. 1), is a disaccharide polyol that consists of glucose and sorbitol in equal parts and is obtained from starch, by hydrogenating maltose or very high maltose glucose syrup[31]. Properties and applications Among polyols, maltitol characterizes with properties the most resembling the ones of sucrose[31,32]. It Maltitol is also a non-cariogenic agent, which characterizes a pleasant sweet taste that is similar to sucrose; however, due to slow absorption, the insulin response associated with its ingestion is significantly reduced[10]. It has been reported that its simultaneous application with short-chain fructo-oligosaccharides in sugar-free food product formulations lowers postprandial glycemic responses[33].

2.5. Mannitol

This 6-carbon sugar alcohol is an isomer of sorbitol (Fig. 1). Mannitol is used as a reserve carbohydrate by some bacteria, fungi, brown seaweeds and some higher plants[34]. However, this process characterizes with low efficiency yielding only 25 % of mannitol in the obtained mixture and a need of elaborate purification step. Thus, fermentative processes have been researched, especially with the use of heterofermentative lactic acid bacteria, resulting in a complete conversion of d-fructose into d-mannitol in mild conditions[35].

2.6. Isomalt

Isomalt is a polyol (synonym for sugar alcohol) made from sugar and used like sugar to replace sugars (like sucrose, high fructose corn syrup, glucose syrup and others) on a one for one basis. Like sugar, it has multiple functions in a product, in particular enabling the development of top-quality confectionery products with specific nutritional/functional characteristics, for example sugar-free products, products that have a low glycaemic or insulinaemic response, reduced calorie products and products that do not promote tooth decay[36,37].

Isomaltulose (6-O-a-D-glucopyranosyl-D-fructofuranose) called palatinose is used in various food products as a noncariogenic nutritive sweetener. It is digestible and the ratio of the digestibility is estimated to be about one-fifth the digestibility of sucrose. Isomalt, produced by reducing isomaltulose, is an equimolar mixture of O-D-glucopyranosyl-1, 6-D-sorbitol and O-D-glucopyranosyl-1, 6- D-manitol. A significant property of isomalt is its ability of to not absorb water until water activity reaching values higher than 0.85. Hence, it is used in hard candies and coatings since it contributes to extend the shelf life of stored products[38,39].

This fact has been associated to the ability of maltodextrin to absorb water forming a protective barrier on the surface of hygroscopic particles, and its capacity to increase the glass transition temperature[40,41].

2.7. Sorbitol

Sorbitol, which has a systematic name d-glucitol (Fig. 1), is a 6-carbon sugar alcohol that was discovered by a French chemist in the berries of the mountain ash in 1872. This polyol can be naturally found in apples, pears, peaches, apricots and nectarines as well as in dried fruits, such as prunes, dates and raisins and in some vegetables[27,42]. Sorbitol is produced from glucose or sucrose, by a catalytic hydrogenation with hydrogen gas and nickel catalyst at high temperatures[43,44]. However, it can be also produced by electrochemical reduction of dextrose in alkaline conditions[27,45].

Some studies show that abdominal issues attributed to sugar alcohols are not caused by sorbitol alone, but by the fructose:glucose:sorbitol ratio consumed[46,47], although additional work is needed[48,49]. Recent findings show a diet low in FODMAPs (Fermentable Oligosaccharides, Disaccharides, Monosaccharides, and Polyols) reduces abdominal issues for individuals with Irritable Bowel Syndrome[43], but again this is not needed for healthy individuals[50,51].

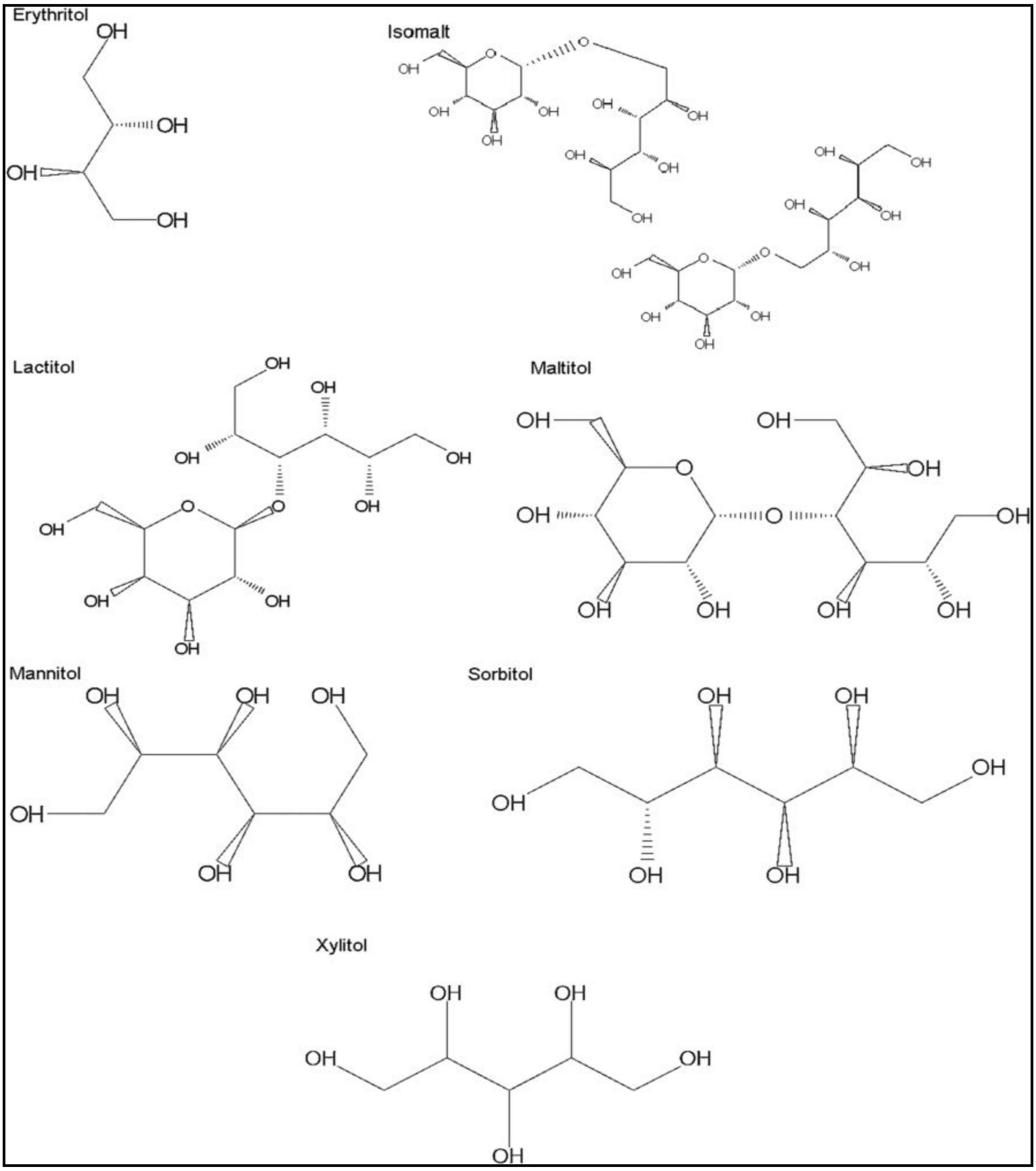

Fig. 1. Chemical structures of sugar alcohols[45].

3. Conclusion

Sweeteners may be used separately or in combination with other sweeteners, as socalled blends[53,54,55]. Numerous studies to improve biotechnological production of sugar alcohols have been reported. Specifically, recent metabolic engineering approaches have focused on utilizing inexpensive and abundant substrates, overcoming catabolic repression, and maintaining redox balance in the microbial platforms. However, not all the fermentative processes are applicable for industrial- scale manufacturing yet because of several issues, such as high production and purification costs, and low productivity. To make the biotechnological processes for sugar alcohol more competitive and economic, diversification of value-added chemicals derived from sugar alcohols, improvement of applicability of inexpensive substrates, such as cellulosic hydrolyzates, and development of efficient bioconversion processes to produce higher-value derivatives of sugar alcohols will be necessary.

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