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Review

Some Alternative Sweeteners (Xylitol, Sorbitol, Sucralose and Stevia): Review

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Abstract

Alternative sweeteners are food additives. They substitute the sugar (sucrose) alone or in combination with each other. Each sweetener has its own properties, may be involved with each other in certain characteristics. They are selected by producers depending on the taste, sweetness, stability and cost which are either nutrient or not nutrient alternatives. Alternative sweeteners have been used to improve the taste of food and/or drink and duplicate the effect of sugar in taste, usually with low calorie value. Some sugar substitutes are natural and some are synthetic. Those that are not natural are, in general, called artificial sweeteners, much less sweetener is required and energy contribution is often negligible. The sensation of sweetness caused by these compounds("sweetness profile") is sometimes notably different from sucrose, so they are often used in complex mixtures that achieve the most natural sweet sensation.

Keywords: Alternative sweeteners, Artificial sweeteners, Sugar alcohol, Sorbitol, Xylitol, Sucralose, Stevia

1. Introduction

Sucrose has numerous significant properties in the food industry, such as strengthening and highlighting the characteristics of components of the other flavor, its work as a preservative, contribution to give volume and osmotic pressure. Nevertheless, it may cause large technical problems in some major applications, such as hydrolysis in acidic systems which result in changes of sweetness and flavor of the product .As a result it has to be dissolved in water before usage in many applications (Al-Dabbas and Al-Qudsi 2012, Walters 2009). As well as the health and nutrition assays which arise due to the consumption of foods containing large quantities of carbohydrates. The decomposition of sucrose gives glucose and fructose, the glucose is very important in our diet system and converts in the body by the process of glycolysis, which occurs by series of reactions leading to the conversion of simple sugars to the smaller molecules specifically pyruvate and ATP (adenosine triphosphate) (McCaughey 2008). Pyruvate metabolizes in the presence of oxygen and leads to produce carbon dioxide, water and ATP. To decompose glucose effectively it needs a force that deals with glucose in the absence of its balance in the blood stream, pancreas is playing this role which secretes glucagon that derived from glycogen. Glucose is released from the glycogen and subjected to the decomposition in glycolysis (Horn 2009). Some people may suffer from the high level of glucose in the blood (hyperglycemia) due to one of two factors , Insufficient insulin due to a defect of secretion and/ or inability of pancreatic beta cells to secrete insulin(Lefebvre et al. 2005,WHO 1999). Some individuals cannot metabolize fructose, but this case is not common (Horn 2009). The reduction of glucose is a difficult task, especially for some individuals who feel the need to sweet taste. The excessive amount of sugar intake causes diabetes and obesity which associated with many diseases especially heart disease, atherosclerosis and susceptibility diabetes and tooth decay and so on (Cherniske 2012). However, health issues, technical and economic difficulties encouraged researchers in food industry to look for sucrose alternatives (artificial or alcoholic) to get almost the same product sweetened by sucrose (Kroger et al. 2006, Nabors 2011, Schardt 2004**).** New developments in alternative sweeteners continue to abound, their history remains fascinating. Sucralose and stevia, among the earliest low-calorie sweeteners, have served as scientific test cases. The numerous sweetener developments throughout the 1990s have facilitated combination use. With the availability of numerous low-calorie and reduced calorie sweeteners and improved technology, higher-quality products can be produced, and in greater quantity. In some parts of the world, foods and beverages are available that contain as many as three or more alternative sweeteners. The use of low-calorie sugar-free products is tripled in the last two decades of the 20th century. Only In the United States, more than 150 million people use these products regularly. The approval of

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these sweeteners for general purpose in the United States and recognition by regulatory agencies around the world that sweeteners have reduced caloric values compared with sucrose (Cardana et al. 2003, Mercola and Pearsall 2006). Alternative sweeteners provide and expand food and beverage choices to control caloric, carbohydrate, or specific sugar intake; assist in weight maintenance or reduction; aid in the management of diabetes; assist in the control of dental caries; enhance the usability of pharmaceuticals and cosmetics provide sweetness in times of sugar shortage; and assist in the cost effective use of limited resources. The ideal sweetener should be water soluble, stable in both food ingredients. Therefore these conditions increase the stability and consequently the shelf-life of the final product. Safety is essential, the sweetener must be nontoxic and metabolized normally or excreted unchanged, and studies verifying its safety should be in the public domain. To be successful, a sweetener should be competitively priced with sucrose and other comparable sweeteners. It should be easily produced, stored, and transported (Schardt 2004).

2. Alternative Sweeteners

Table 1 shows relative sweetness, ADI, nutrient and not nutrient sweeteners of some sweeteners (natural, alternatives and artificial) compared with sucrose (Kroger et al. 2006, Rothen 2005).

2.1. Xylitol

It is organic compound and one of four isomers of any (Pentane-1,2,3,4,5-pentol) with five carbon atoms, called wood sugar or birch sugar, and has other names are Penta- hydroxy pentane, Xylite, Polyhydric acid and Polyalcohol. It is used as a natural alternative sweetener on the taste buds (Sarah 2009). It is found in small amounts in a variety of fruits and vegetables (Makinen et al. 2007) and is formed as a normal intermediate in the human body during glucose metabolism. Xylitol has been shown to be valuable in the prevention of dental caries because it is not an effective substrate for plaque bacteria (Leah 2011). Because of its largely insulin-independent metabolic utilization, it may also be used as a sweetener in the diabetes diet and as an energy source in parenteral nutrition. As a sweetening agent, xylitol has been added in human diet since 1960s (Teya 2008).

2.1.1. Production of Xylitol

Xylitol produces by a chemical method which is based on the hydrogenation of wood sugar (xylose or xylose rich with hemicellulose) in presence of nickel as a catalyst (Salmi et al. 2003). Xylitol also can be produced by biotechnological method based on its metabolism in yeast, which is a key factor appropriate and effective in this way, there are groups of yeasts e.g. *Candida tropicalis* which have the ability to metabolize wood sugar as a source of carbon and prefer urea or urea and casamino acids (Sreenivas et al. 2004).

2.1.2. Metabolism of Xylitol

Two different metabolic pathways are available for the use of xylitol:

(a) Indirect metabolism by means of fermentative degradation of unabsorbed xylitol by the intestinal flora. Xylitol is slowly absorbed from the digestive tract, after ingestion of large amounts, only a certain proportion of the ingested xylitol is absorbed and fermented by the intestinal flora. Beside minor amounts of gases of H_2, CH_4 and CO_2, the end-products of the bacterial metabolism of xylitol are mainly short-chain, volatile fatty acids, (i.e., acetate, propionate, and butyrate). These products

Table 1. The sweetness of some sweeteners (natural, alternatives and artificial) compared with sucrose

Sweeteners	Not Cause Tooth Decay	Cause Tooth Decay	Not Nutrient Sweeteners (w/o calories value)	Nutrient Sweeteners (kJ/gm)	Relative Sweetness	*ADI of Sweeteners/ kg body weight / day
Natural sweeteners						
Sucrose	-----	Yes	-----	16.74	1	Unspecified
Glucose	-----	Yes	-----	16.74	0.7	Unspecified
Alternatives sugar , sugar alcohol						
Xylitol	Yes	No	------	10.04	1	Unspecified
Sorbitol	Yes	No	------	10.04	0.6	Unspecified
Artificial sweeteners						
Stevia, stevia Rebaudiana)	Yes	No	Yes	Yes	250-300	4 mg
Sucralose (Splenda)	Yes	No	Yes	Yes	600	15 mg

*(ADI) acceptable daily Intake (Kroger et al. 2006, Rothen 2005).

are subsequently absorbed from the gut and enter the mammalian metabolic pathways.

(b) Direct metabolism of absorbed xylitol in the mammalian organism, mainly in the liver, a direct metabolic pathway is available for the portion of xylitol that is absorbed unchanged from the gastrointestinal tract (Nabors 2001, Mäkinen 2004). The metabolism of xylitol and its general relationship to the carbohydrate metabolism by means of the pentose phosphate pathway is shown in Figure 2.

2.1.3.Safety of Xylitol

Xylitol is safe for people with diabetes, almost it maintains the level of blood glucose in the normal limits because of low, slow and incomplete absorption; therefore; it could be used in the diet food because of the suppression of glucose absorption, also to suppress appetite (Salmi et al. 2003) and it is safe for teeth because it is unuseful for the microflora in the mouth as *Streptococcus mutans* and *Streptococcus salivarius*) Leah 2011).

2.2. Sorbitol

Sorbitol is widespread in nature, as it exists widely in the plant kingdom and in many fruits such as plum, peaches, apples, berries, cherries and pears. It's relative sweetness is equal to 60% of the sweetness of sucrose with a third of the caloric, giving the cold mouth feeling because of its ability to absorb the heat of solution compared to other sugars as well as to give it a sense of softness, sweetness and pleasure (Vincent 2011). Sorbitol has existed as commercial products for more than 60 years. Today, sorbitol is used in food, confectionery, oral care, pharmaceutical, and industrial applications because of its unique physical and chemical properties.

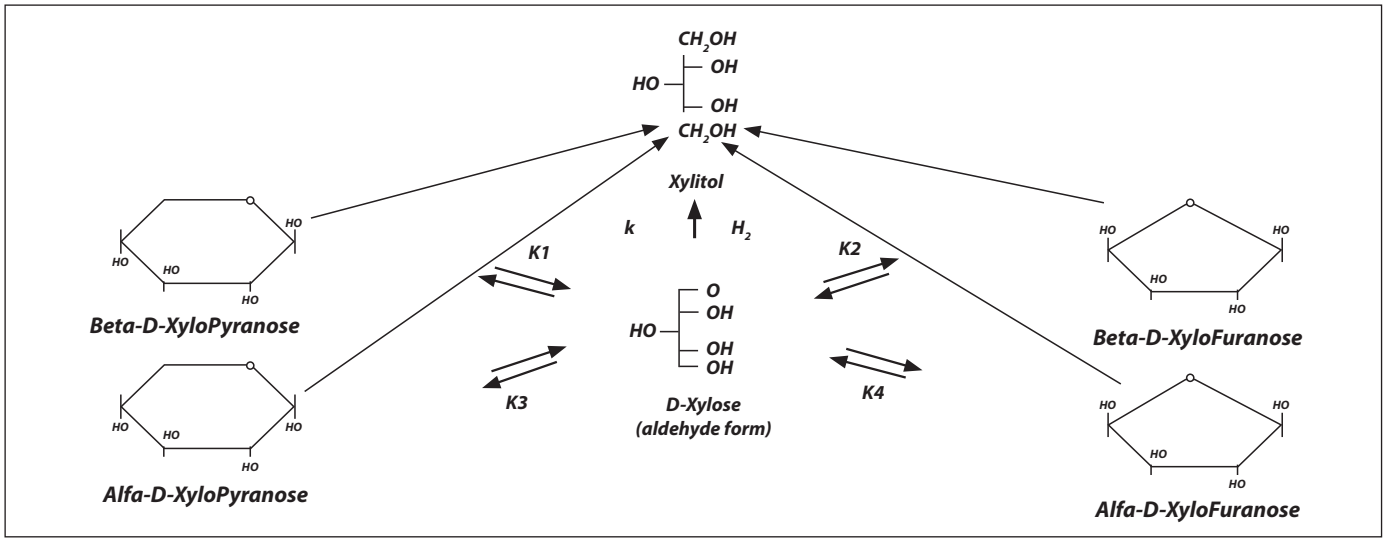

Figure 1. The chemical production of xylitol (Designed by authors).

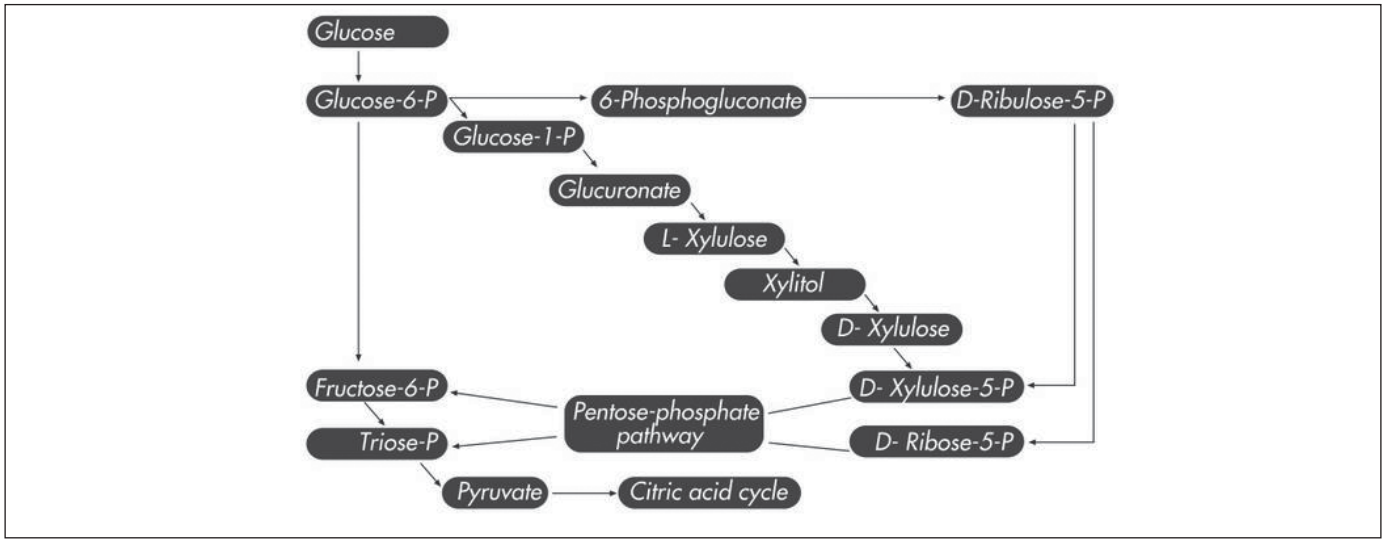

Figure 2. Metabolism of xylitol (Designed by authors).

The Joint Committee on Food Additives (JECFA) mentioned specifications of sorbitol which has been modified in 2001 and is being a wet white powder as it contains 1% water or a crystal or flakes or granules, the molecular weight 182¸17, purity not less than 97% based on a dry weight and not less than 91% based on wet weight, chemical formula $C_6H_{14}O_6$ and is used as a sweetener, moisturizer, a component of strength, stabilizer and increasing volume agent, it has a high solubility in water and slightly in ethanol (Kusserow et al. 2002).

2.2.1. Production of Sorbitol

Sorbitol is produced from the catalytic hydrogenation of glucose (Kusserow et al. 2002), sucrose and starch (American Dietetic Association 2004). Crystalline sorbitol is made by further evaporating the sorbitol solution into molten syrup containing at least 99% solids. The molten syrup is crystallized into a stable crystalline polymorph that has one single melting point(99–101°C) and heat of fusion (175.2 kJ/g, assuming 184 kJ/g) represents a fully crystallized crystalline sorbitol). The stable polymorph of sorbitol is known as gamma (γ) Most commercially available crystalline sorbitol is the (gamma polymorph) (Sreenivas et al. 2004). Mentioned (Ahmed et al. 2009) that the possibility of production of dry sorbitol from three six-sugars are D- glucose, fructose and D-Sorbose, the best source of its production is the glucose because of its presence in a wide and low cost. That by the process of hydrogenation, by using nickel catalysts, and using a temperature of 120-160 C and pressure of 70-140 bar, both of glucose and sorbose produce sorbitol but the fructose produces both sorbitol and mannitol. The production of sorbitol from glucose syrup is shown in Figure 3.

2.2.2. Metabolism of Sorbitol

Sorbitol is widely accepted by the food and pharmaceutical industries as nutritive ingredient because of its ability to improve the taste and shelf-life of regular foods and special dietary products. Sorbitol is slowly absorbed into the body from the gastrointestinal tract and metabolized by the liver mainly as fructose, a carbohydrate that is highly tolerated by people with diabetes. Sorbitol is absorbed and metabolized in the liver by a pathway located entirely in the cytoplasmic compartment, demand for extra insulin. The initial steps in sorbitol metabolim in the liver, its uptake by liver cells and conversion to glucose is independent of insulin, but the subsequent use of glucose by the muscle and adipose tissues is influenced by insulin (Nabors 2001, Oku and Nakamura 2002). Figure 4 shows Sorbitol and mannitol metabolism (Nabors 2001).

2.2.3. Safety of sorbitol

Many studies showed that large amounts of sorbitol (20-30 g / day) has lead to abdominal pain. Diabetes should consume sorbitol within the specified amounts. Sorbitol naturally produced in human body from glucose, Excessive amount of sorbitol may be turned to glucose then accumulate in kidneys leading to damage them, also causes damage to nerve tissue and retina.Sorbitol is not recommended for individuals with high galactose level in blood (Brownlee 2001). American organization for biological experiments indicated no risk of sorbitol intake within specified levels. FDA recommended 50 g / day as acceptable daily intake of sorbitol for humans (Doheny 2008).

2.3. Stevia

Stevia is shrub of *Chrysanthemum* 'Asteraceae', family its height is 80 cm, and there are about 150-300 type of them, called *Stevia rebaudiana* Bertoni, its native is northeastern Paraguay in South America. It has been also cultivated in China, Brazil, Europe, Canada and Japan, and used by the Japanese since the 20 years old (BIHW 2009). The word Stevia refers to the whole plant and the paper contains compounds that sweet and non sweet Compounds.

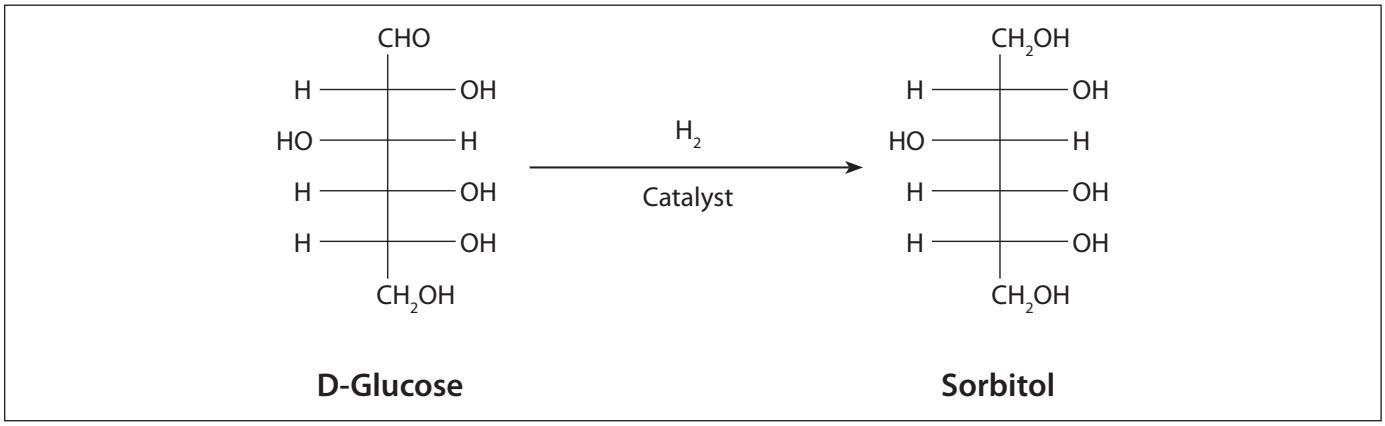

Figure 3. Production of sorbitol from glucose syrup (Ahmed et al. 2009).

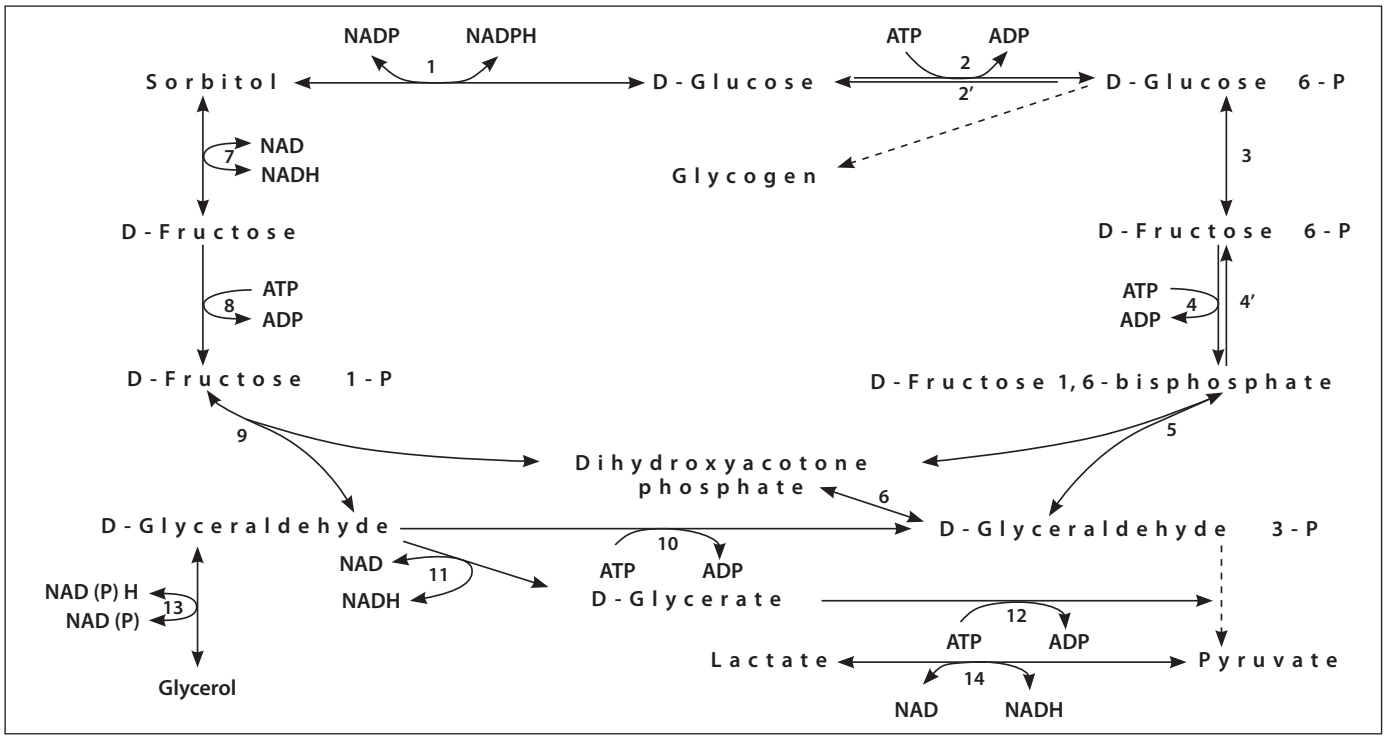

Figure 4. Sorbitol and mannitol metabolism (Nabors 2001).

The sweet compounds called glycosides which is double turbine with a sweet taste (WHO 1999). Stevioside is a white crystalline material with a melting point of 196–198°C, an optical rotation of 39.3 degrees in water, an elemental composition of $C_{38}H_{60}O_{18}$, and a molecular weight of 808.88. Stevioside is only sparingly soluble in water but is highly soluble in ethanol. Rebaudioside A is considerably more water soluble than stevioside because it contains an additional glucose unit in its molecule. Stevioside is relatively stable under normal elevated temperatures involved in food processing and does not turn brown on heating or ferment during use. The compound does not precipitate. Stevioside is permitted for use in distilled liquors, unrefined rice wines, in South Korea 1984, confectionery, soy sauce, and pickles, although not so far in bread, baby foods, dairy products, and as a tabletop sweetener. There is an active market for *S. rebaudiana* products in the United States (Nabors 2001).

2.3.1. Production of Steviol glycosides

The production of stevia sweeteners by extraction methods (Abu-Arab et al. 2010**).**

Extraction in water; soaked in worm water at 15:1 v / w for 3 hours, then it is filtered and purified using calcium hydroxide, the filtrate passes through the ion exchange column to remove unwanted pigments and then concentrate by rotary evaporator at a temperature 45°C. Extraction in methanol; The dry leaves soaked in methanol at 4:1 v / w for 7 hours. The filtrate by evaporation with rotary evaporator at a temperature of 45**°**C and the remaining washes by ether and extracts with butanol several times to remove pigments and purified by crystal process in temperature 5**°**C. Figure 5 shows the chemical composition of stevia sweetener (BIHW 2009).

2.3.2 Metabolism of Stevia Compounds

Only limited data are available on the in vitro and in vivo metabolism of stevioside and other S. rebaudiana sweet constituents. An initial investigation in which stevioside and rebaudioside A were degraded to steviol by rat intestinal flora in vitro was reviewed previously. Steviol has also been found as a major metabolite of stevioside when a tritiated form of the compound was fed to wistar rats at an oral dose of 125 mg/kg.The biological half-life of stevioside was estimated to be 24 hr, and 125 hr after compound administration, the highest percentages of radioactivity were found in the feces, followed by expired air and urine. It was concluded that although a portion of orally administered stevioside was excreted unchanged in the feces of the rat, most of it was degraded by the intestinal bacterial flora to steviol, steviolbioside and glucose, which were then absorbed in the cecum (Nabors 2001). Absorbed glucose was metabolized and excreted in the expired air as carbon dioxide and water, where as steviol was conjugated in the liver and excreted into the

bile. It was also inferred from the results of biliary and fecal excretion that enterohepatic circulation of steviol occurred. JECFA concluded, based on many studies that conducted to determine the conversion outside the human body for two glycosides rebaudioside- A and stevioside and incubation with microflora that isolated from human feces selective broth which added to it two glycosides by using HPLC, they are fully degraded to the aglycon steviol in 10 and 24 hours respectively, and the decay times vary due to linkage C19: 1 in stevioside degraded rapidly by microflora to steviol and a half glucose while the linkage 13:1 C in rebaudioside A more resistant to degradation by this microflora (Ishii and Brache 1995). It was concluded that the microflora in the human intestine not able to analyze the steviol therefore it comes out with the urine in the form of steviol glucuronide and this means that metabolized compounds leave the body and do not accumulate in it (Hutapea et al.1999). Acceptable daily intake of stevia is 4 mg/kg body wt./day (Brownlee 2001).

2.3.3. Safety of stevia

Chronic oral toxicity study performed in male and female wistar rats fed a diet containing 85% pure stevioside (0, 0.2, 0.6, and 1.2%), result showed no-effect of stevioside was equivalent to 1.2% of the diet. The rats did not show any treatment-related changes in growth, general appearance, and clinical biochemical values relative to control. It was projected from this study that an acceptable intake of stevioside in humans 7.94 mg/kg/day.

The LD_{50} values for steviol in hamsters (which were more susceptible to this compound than either mice or rats) were 5.20 and 6.10 g/kg body weight for males and females, respectively. Death was attributed to acute renal failure, and severe degeneration of the proximal tubular cells was observed histopathologically (WHO 1999, Nabors 2001).

2.4. Sucralose

Sucralose was discovered in 1976 during the consideration of a collaborative research between Tale and Lyle sugar

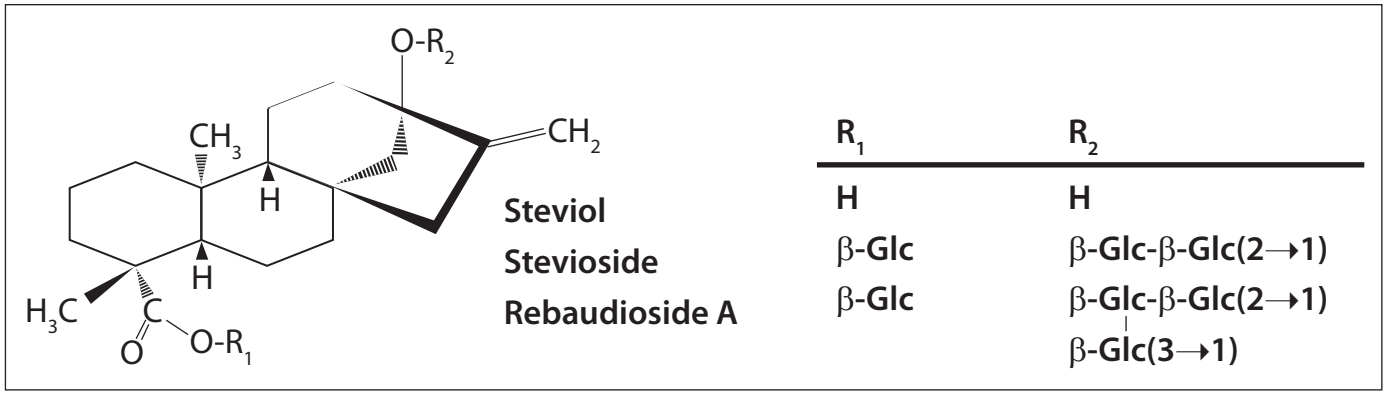

Figure 5. The chemical composition of stevia sweetener (BIHW 2009).

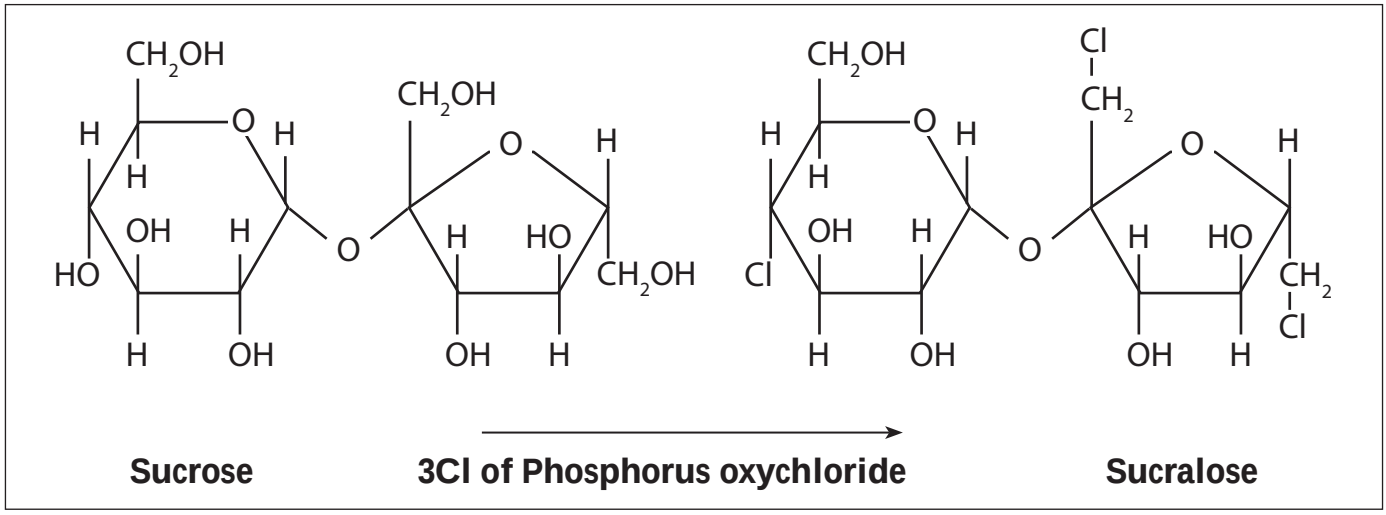

Figure 6. The production of sucralose (Mercola 2005).

refinery Ltd and the College of Queen Elizabeth at the University of London (Knight 1994, Lebedev et al. 2010**)** in trying to find ways to use sucrose in the production of chemical intermediate agents , and in 1989 conducted Hough and Khan Studies on these sweeteners that they had been replaced by groups hydroxyl with halogens in the molecule of sucrose and it has been observed that these halogens have been able to change the sweetness of the molecule, chlorine and bromine both are highly soluble in water, but found that the bromine is difficult treatment and has little effect in the strength of desalination (Hough and Khan 1989).This was ruled out and choose chlorine Which form sucralose that is chemical name 1,4,6-Trichlorogalactosucrose (Ishii and Brache 1995), but the trade name is splenda, produces in purity of 98% (Knight 1994). For this reason, it was chosen as an ideal sweetener. The selective chlorination of the sucrose molecule produced remarkable changes to the sweetness intensity and stability of sucrose, without compromising taste quality. Sucralose has a pleasant sweet taste similar to sucrose and has unpleasant aftertaste. Sucralose is a white, crystalline, no hygroscopic, free flowing powder. The sweetener is highly soluble in water, ethanol, and methanol and has negligible effect on the pH of solutions. The viscosity of sucralose solutions is similar to that of sugar the reason that microorganisms responsible for plaque formation cannot use the sweetener, and thus sucralose is noncarcinogenic (Nabors 2001).

2.4.1. Production of sucralose

The production of sucralose occurs by linking of chlorine with sucrose. The process made in five stages, ,it has been replaced by three groups hydroxyl selectively with three atoms of chlorine in the molecule of sucrose (Ishii and Brache 1995) as in figure (6):

2.4.2. Metabolism of sucralose

Many studies have shown that the majority of sucralose affordable and non-absorbed out with the faeces unchanged, and the majority of absorbed out with the urine unchanged too and its rate up to 1-2%, and rates of metabolized of sucralose in experimental animals vary according to type of animal (Lebedev et al. 2010).

As appear that Ratio of metabolized sucralose haven't been engaged in any metabolic pathways that responsible for the balance of glucose in rats and humans (Mercola and Pearsall 2006).

2.4.3. Safety of sucralose

More than 100 scientific studies have been conducted over the past 20 years to evaluate the safety of sucralose for human consumption. Recently, the safety database for sucralose was published in a peer-reviewed supplement of Food and Chemical Toxicology, ''Sucralose Safety Assessment'' No evidence exist that the consumption of sucralose or its hydrolysis products would cause any untoward effects. Sucralose is nontoxic and does not hydrolyze or dechlorinate after ingestion (Rencuzooullari 2006). A small amount of hydrolysis of sucralose can be found in products, depending on pH, time, and temperature. The animal studies clearly demonstrate the overall safety of sucralose even under lifelong, high-dose test conditions that would exaggerate any health effects. Studies included evaluation of animals that were exposed to sucralose from conception throughout normal life span and with amounts that far exceed the probable maximum human consumption. In addition, the hydrolysis products of sucralose were subjected to almost the same level of testing as sucralose, including a separate cancer study. Metabolism studies indicate that the dog, rat, mouse, and man metabolize sucralose similarly. Therefore, the results of the safety studies conducted on sucralose in animals can be extrapolated to man with confidence (Mercola and Pearsall 2006).

Table 2. Ratio of metabolized sucralose in different types of experimental animals and humans (Lebedev et al. 2010).

Experimental animals	Ratio metabolized of sucralose
Rats and mice	Less than 10%
Rabbits	22-30%
Human	20-30%
Dogs	30-40%

3. Conclusion

Sucrose replacement by artificial and alcoholic sweeteners is to reduce calorie content. These sweeteners are convenient for diabetes , they do not require insulin for their metabolism. They do not cause teeth decay because they do not provide the suitable environment for microorganisms growth in the mouth. It has been concluded that the use of alternative sweeteners led to a reduction of body weight, blood sugar level, and blood lipids as cholesterol, triglycerides, LDL and increased HDL levels. Despite of numerous approvals on artificial sweeteners, but there is a need for further studies using experimental animals about the impact of artificial sweeteners on the endogenous organs such as heart, lungs, liver and spleen and study the storage of glycogen in liver.

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