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Sucrose substitutes and their role in caries prevention

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Many non- or low-cariogenic sucrose substitutes are currently available and are found as ingredients of a variety of candy, chewing gum, and drinks. Recently the role of sugar alcohols in promoting remineralisation of enamel has attracted much attention. Thus, the dental profession needs to understand the general characteristics and features of sugar substitutes to provide advice on oral health to patients as well as the general public. There are two critical requirements for sucrose substitutes, namely, being nutritionally appropriate and not being detrimental to the overall general health of the individual. The use of a greater variety of confectionary containing sucrose substitutes and the development of new substitutes with high nutritional value are essential in the battle against caries. In this paper we review in detail the characteristics of sucrose substitutes currently in use, their role in caries prevention and promotion of oral health.

Key words: Sucrose substitutes, low-cariogenicity, caries prevention

The main health benefits of sucrose substitutes in foods and drinks are in their contribution to controlling body weight and diabetes and in promoting oral health. Depending on which sweeteners are under consideration, these goals assume different degrees of importance. Two important requirements of sucrose substitutes are that they are not detrimental to the health and well-being of the individual and that they are nutritionally appropriate for the specific food and drink.

This paper focuses on the role of sucrose substitutes in promoting oral health. Since the 1940s, the principal concern among dental professionals has been the high worldwide prevalence of dental caries. Results from several controlled human studies[1-5], a study on patients with hereditary fructose intolerance[6] and laboratory investigations[7-11] carried out over the past 50 years have shown that sucrose plays a major role in the initiation and progression of dental caries. Thus, the Turku Sugar Studies fired the search for non-cariogenic sucrose substitutes. At that time, many sucrose substitutes of non- or low-cariogenic character were developed.

Consequently, several sugar alcohols, including xylitol, have been introduced into many types of candy and chewing gum and high-intensity sweeteners have been used in drinks and sweets. By the 1970s, the prevalence of dental caries in young children in industrialised countries had shown a dramatic decline[12-18]. While the widespread use of fluoride is no doubt the major reason for this decline, there are still populations at high risk of dental caries. Moreover, a similar decline in dental caries prevalence has not been demonstrated among older teenagers and adults. Furthermore, as the age of populations increases, root caries has become considerably more prevalent[19,20]. Also, recently, the role of foods in promoting remineralisation of initial dental carious lesions has also attracted much attention[21]. Thus, the situation regarding the role of sucrose substitutes in targeting dental caries prevention has been changing. If the appropriate use of sucrose substitutes is to be promoted, the dental profession needs to understand their general characteristics as well as their systemic and local effects. In this paper, we review the sucrose substitutes currently in use and their role in caries prevention and dental health promotion.

Methods of evaluating the cariogenicity of sugar substitutes and foods

A number of different approaches have been used in an attempt to develop reliable methods for measuring the cariogenic potential of individual foods. These include:

- *In vitro* models[22,23]
- Animal models[24-28]
- *In vivo* monitoring of acid production by human dental plaque bacteria using indwelling pH sensor (human plaque pH method)[10,11,29-31]
- Intraoral cariogenicity tests or demineralisation/remineralisation models[32,33].

At present, all four of the above examinations are required to evaluate the cariogenicity of an individual sugar substitute. The human plaque pH method is used to evaluate the non-cariogenicity of foods containing sugar substitute (e.g. chewing gum, chocolate, and candy). Intraoral cariogenicity tests have been used to evaluate the capacity for remineralisation of non-cariogenic foods, sugar alcohols such as xylitol and maltitol and the additives.

Characteristics and dental aspects of sucrose substitutes

For sucrose substitutes to be used in promoting oral health they must naturally be safe substances. This means they must be non-toxic, chronic or acute and non-oncogenic, and they must also have a temperate effect on the digestive tract. Most of the sucrose substitutes described below are effectively non-toxic in the terminology of Loomis's classification[34]. *Table 1* summarises the characteristics of sucrose substitutes currently in use in the Japanese food industry.

Classification of sweeteners

Sweeteners, which give food a sweet taste, are classified into carbohydrate sweeteners (caloric) and non-carbohydrate sweeteners (non-caloric). Carbohydrate sweeteners include sucrose, various oligosaccharides, starch sugars and sugar alcohols. Sucrose is chemically stable both as a concentrated solution and in its crystal form. It provides a high-quality sweet taste and has an acceptable texture and shape, and because of this it has remained the most popular sweetener. Oligosaccharides include palatinose, fructo-oligosaccharide, galacto-oligosaccharide, lacto-oligosaccharide and xylo-oligosaccharide. Starch sugars include glucose, starch syrup, HFCS, powdered sugar, maltose, invert sugar, and fructose. Sugar alcohols include erythritol, sorbitol (sorbit), mannitol (mannit), xylitol (xylit), maltitol, lactitol, Palatinit™, and reducing starch syrup. Non-carbohydrate sweeteners are divided into chemically synthesised sweeteners, including saccharin, aspartame and sucralose, and those obtained from plants, including stevioside, thaumatins, and monellin. These are termed high-intensity sweeteners.

Oligosaccharide

Palatinose (isomaltulose), <a-D-glucopyranosyl-D-fructose, $C_{12}H_{22}O_{11}$>
  Palatinose is a disaccharide of glucose and fructose.

Table 1 Characteristics of noncariogenic sucrose substitutes

| | Oligosaccharide | Sugar alcohol | | | | | | High intensity sweetener | | |
| | | Monosaccharide alcohol | | | Disaccharide alcohol | | | | | |
	Palatinose	Erythritol	Xylitol	Sorbitol	Maltitol	Lactitol	Palatinit™	Stevia sweetener	Aspartame	Sucralose
Sweetness	0.42	0.7-0.8	1.0	0.6-0.7	0.75-0.80	0.30-0.40	0.45	150-300	160	600
Energy (kcal/g)	4	0	3	3	2	2	2	0	4	0
Absorption in small intestine (enzyme involved in digestion)	Almost all (isomaltase)	Almost all	Mostly	Mostly	Partial (maltase)	Partial (lactase)	Partial (isomaltase)	None	All	None
Absorption in large intestine	Almost none	Almost none	Partial*	Partial*	Almost Complete*	Almost Complete*	Almost Complete*	A part of the sugar component	None	None
Elicitation of insulin release	Weak	None	None	None	None	None	None	None	None	None
Side-effects**	No	No	Yes	Yes	Yes	Yes	Yes	No	No	No
Cost(yen/kg)[114]	1,000	700-800	800	130	250-300(syrup) 450-500(crystalline)	400-500	400	6,000	10,000	60,000
Consumption per year[114](t)	150	5,000	8,500	150,000	25,000	1,300	4,000	1,300	200	-

* The sugar is fermented by enterobacteria in the large intestine and is absorbed as organic acid.
** Side effects when taken in excess are abdominal discomfort, flatulence, softened stools, and diarrhea.

The structural formulae of palatinose and sucrose are shown in *Figures 1* and *2*. It is found naturally in small quantities in honey and cane juice, and can be obtained from sucrose using a transferase produced by *Protaminobacter rubrum*. The sweetness of palatinose is 42% that of sucrose and, while its quality of taste resembles that of sucrose, the sweet taste disappears faster. Palatinose is not transported through the intestinal mucosa but is hydrolysed into glucose and fructose by intestinal disaccharases in the lower small intestine, and these monosaccharides are subsequently absorbed. The speed of palatinose hydrolysis is slower than that for sucrose. The available energy value of palatinose is 4kcal/g. The benefits of palatinose are that it provides the same amount of energy as sucrose and glucose, and it does not induce diarrhoea. For this reason, it is considered an excellent sweetener for sweets and drinks for infants, children and diabetic patients[35]. Furthermore, little or no acid production activity by a number of serotypes of mutans streptococci and other oral streptococci has been demonstrated following fermentation of palatinose[36], and acid production by dental plaque suspensions was noticeably lower in the presence of palatinose compared with sucrose[37]. It has also been found that the plaque suspensions produce little or no lactate following fermentation of palatinose[38].

In addition, no water-insoluble glucan was synthesised from palatinose by the crude glucosyltransferase preparation obtained from *S.sobrinus* 6715[36], and the inhibition rate correlated directly with the concentration of palatinose. The mechanism of the inhibition has also been clarified. Palatinose appears to function as a receptor for the glucosyl base of sucrose resulting in the formation of a specific oligosaccharide[27]. In experimental caries studies using rats, the caries scores were consistently lower in rats fed a palatinose diet compared with those fed a sucrose diet[27,39], and colonisation by *S.mutans* was minimal in the palatinose-fed group compared with the sucrose-fed group. In a human study, significantly lower acid production was found following mouthrinsing with palatinose as compared with glucose[40]. The chemical character and dental and medical aspects of palatinose have been summarised comprehensively by Takazoe[41]. As a result of this positive study, candy and dairy product drinks containing palatinose are being marketed today.

Sugar alcohol (Polyol)

Sugar alcohol is the general term for the chain-like polyalcohol obtained by reducing the carbonyl group of sugars. Generally, in naming the sugar alcohol, '-ose' is changed into '–itol' or '-it'.

The general characteristics of sugar alcohols are non-fermentability, a moistening effect, the maintenance of quality and heat resistance. The Maillard reaction does not occur easily, and thus browning and burning of food are prevented. Sugar alcohols have an oxidation suppression effect on protein degeneration, so permitting the retention of freshness in fish and animal meat. Moreover, they help to reduce caloric intake due to their slow digestion and do not stimulate the secretion of insulin. There is also no rapid elevation of the blood glucose level (in application as sweeteners for diabetic patients), they do not increase lipoprotein-lipase activity, thus helping to prevent obesity, and they suppress oxidation of vitamin C. Sugar alcohols have a cool feeling in the mouth and this feeling results from the fact that dissolution of sugar alcohol in water is an endothermic reaction.

Important benefits of sugar alcohols from a dental perspective include their non- and little fermentability by oral microorganisms[37, 42-44] (non-cariogenic nature) in human dental plaque and their ability to promote remineralisation of demineralised enamel[21,45-54].

However, the general demerits of sugar alcohols, except erythritol, are side effects such as abdominal discomfort, flatulence, softened stools, and diarrhoea when taken in excess.
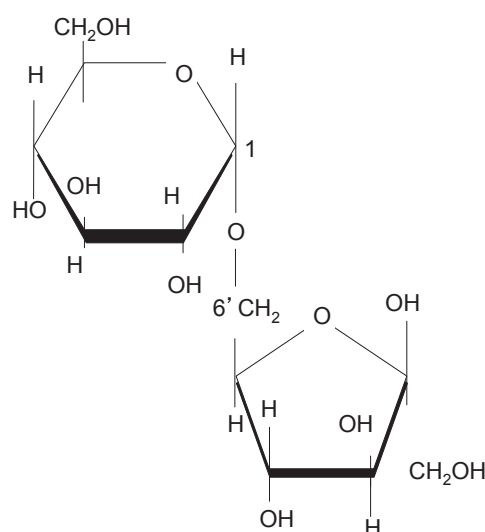
Figure 1. Structural formulae palatinose (Isomaltulose) (α-D-glucopyranosyl-1,6-D-fructose, $C_{12}H_{22}O_{11}$)
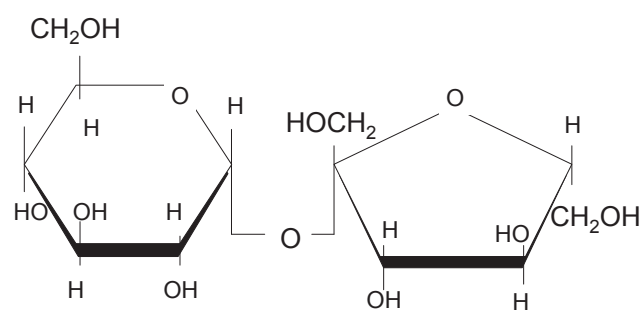
Figure 2. Structural formulae of sucrose (α-D-glucopyranosyl-1,4-D-fructose, $C_{12}H_{22}O_{11}$)

Erythritol <1, 2 and 3, 4-Butanetetrol, $C_4H_{10}O_4$>

The sugar corresponding to erythritol (4 carbons) is an erythriose. The structural formula of erythritol is shown in *Figure 3*. Erythritol exists widely in nature, including in lichen, mushrooms, fruits, fermented foods, and the body fluids of mammals. It is also obtained from the fermentation of glucose by yeast. The sweetness of erythritol is 70-80% that of sucrose. Erythritol is able to mask the bitter taste of sweeteners such as stevioside, so making it comparable to sucrose in this respect. As a result, it is used to improve the taste of this high-intensity sweetener. Erythritol is predominantly absorbed promptly from the small intestine (90% or more), and most of the absorbed sugar is excreted in urine without being metabolised. Therefore, it does not provide an energy source (the energy value is 0kcal/g), nor does it cause diarrhoea.

Erythritol can be classified as a non-cariogenic sweetener, only one study has reported its cariogenicity[55]. In that study, *S.mutans* PS-14 and *S.sobrinus* 6715 did not attach to glass in the presence of erythritol, indicating that erythritol does not appear to be used by mutans streptococci for the synthesis of water-insoluble glucans. A significantly lower caries score was observed in the rats infected with *S. sobrinus* 6715 and fed with erythritol.

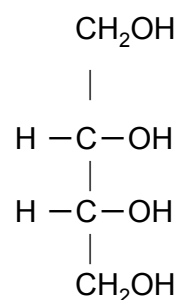## Xylitol <xylo-pentane -1, 2, 3 and 4, 5-pentol, $C_5H_{12}O_5$>

The sugar corresponding to xylitol (5 carbons) is xylose. The structural formula of xylitol is shown in *Figure 4*. Xylitol is found in fruits, such as plums and berries, and in vegetables. It is also obtained by hydrogenation of xylose obtained during purification of xylan from cottonseed cake and trees, such as oaks and white birches.

Although the sweetness of xylitol is similar to that of sucrose, the sweet taste appears and disappears a little faster and the rapid dissolution of xylitol in water results in a cool feeling in the mouth. A large portion of ingested xylitol is directly absorbed by the small intestine and subsequently metabolised. The remainder reaches the large intestine where it is fermented by enterobacteria. The available energy value of xylitol, as a nutrition indicator, is 3kcal/g.

Many papers on the non-cariogenic nature of xylitol have been published since the 1970s. The results of several epidemiological studies indicate that xylitol is non-cariogenic[3,4]. The results of *in vitro* studies have also shown that xylitol is not metabolised by mutans streptococci or other microorganisms in the oral cavity[42]. In support of this, it has also been found that plaque pH is not reduced following the intake of xylitol[37,56 57]. Moreover, a bacteriostatic effect of xylitol on mutans streptococci has been demonstrated[58-60]. Results from biochemical studies suggested that xylitol is transported via the fructose-PTS of *S.mutans* and the xylitol-5-phosphate created by this pathway is not metabolised.

It was believed that the xylitol-5-phosphate may have undergone eventual dephosphorylation and was perhaps exported at the expense of ribitol-5-phosphate[61]. This is the so-called xylitol futile cycle[62,63]. Xylitol decreases plaque formation[64-67] and the long-term intake of xylitol has been reported to reduce the *S.mutans* level in saliva and plaque[65-67]. Habitual xylitol consumption by mothers has also been shown to result in a statistically significant reduction of the probability of mother-child transmission of mutans streptococci[68,69] and dental caries in their children[70]. Adding xylitol to fluoridated dentifrices (10-20%) has a similar effect[71,72]. However, it should be noted that the caries reduction is not equated with a significant microbial effect. The exponential reduction in colony forming units (CFUs) has not been shown. Possibly, the modest reduction in mutans streptococci is due to the 'fasting' effect of xylitol on oral microorganisms. The adaptation of *S.mutans* to xylitol has been recognised[73-77], although the effect of xylitol-insensitive strains of *S.mutans* on fermentable carbohydrates and on glucan synthesis from sucrose has not been clarified.

It is generally assumed that xylitol is non-cariogenic and an extremely effective sweetener in sweets, but its anticariogenic effect is yet to be supported by evidence-based data.

Figure 3. Structural formulae erythritol (1, 2 and 3, 4-Butanetetrol, $C_4H_{10}O_4$)
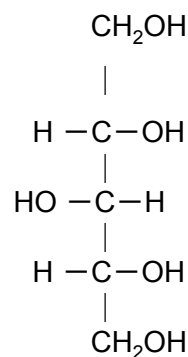
Figure 4. Structural formulae of xylitol (Xylo-pentane -1, 2, 3 and 4, 5-pentol, $C_5H_{12}O_5$)

Sorbitol <D-glucitol, $C_6H_{14}O_6$ >

The sugar corresponding to sorbitol (6 carbons) is glucose. There are three types of crystal: alpha, beta, and gamma. The structural formula of sorbitol is shown in *Figure 5*. Sorbitol is the sugar alcohol most frequently added to food, both in solid and in liquid form. It is found naturally in fruits, including apples, pears, and apricots, as well as seaweed and can be obtained by hydrogenation of glucose. The sweetness of sorbitol is 60-70% that of sucrose, and the sweet taste disappears a little faster than that of sucrose. Sorbitol is metabolised in the same manner as xylitol, and the available energy value is 3kcal/g.

How mutans streptococci use sorbitol as a carbon source is well understood from a dental perspective. Although acid formation in the bacterial plaque can occur, sorbitol is considered non-cariogenic in nature because of the slow acid production during its metabolism by oral microorganisms[78-80]. It is often used as a negative control in dental plaque acid production studies.

Maltitol <4-O-alpha-D-glucopyranosyl-D-glucitol, $C_{12}H_{24}O_{11}$ >

Maltitol, also termed reducing maltose, is a disaccharide alcohol of glucose and sorbitol (*Figure 6*), obtained by the hydrogenation of maltose. The sweetness of maltitol is 75-80% that of sucrose and its quality of taste resembles that of sucrose. A portion of the ingested maltitol is hydrolysed by maltase in the small intestine, but most reaches the large intestine where it is fermented by enterobacteria. The available energy value is 2kcal/g.

Results from several studies have shown that maltitol is non-cariogenic in nature. Evaluation of maltitol *in vivo* by the pH response of dental plaque using an intra-oral apparatus[31] and *in vivo* by experimental enamel demineralisation[81] has demonstrated that maltitol does not lower plaque pH[80]. It has also been demonstrated that 14 strains of oral streptococci, including mutans streptococci, do not utilise maltitol or produce sufficient acid in its presence to demineralise tooth enamel[82]. Furthermore, maltitol does not serve as a substrate for glucosyltransferases of either *S.mutans* MT8148R or *S.mutans* 6715 for the synthesis of water-insoluble glucan[82]. A significantly lower caries score was also reported for rats fed maltitol compared with those fed sucrose[82].

Lactitol <4-O-beta-D-glactopyranosyl-D-glucitol , $C_{12}H_{24}O_{11}$ >

Lactitol, also termed reducing lactose, is a disaccharide alcohol of galactose and sorbitol (*Figure 7*) obtained by the dehydrogenation of lactose. Its sweetness is 30-40% that of sucrose, and its quality of taste resembles that of sucrose. A proportion of ingested lactitol is hydrolysed by lactase in the small intestine, but most reaches the large intestine where it is fermented by enterobacteria. The available energy value of lactitol is 2kcal/g.
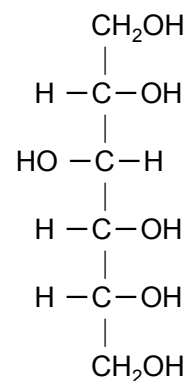

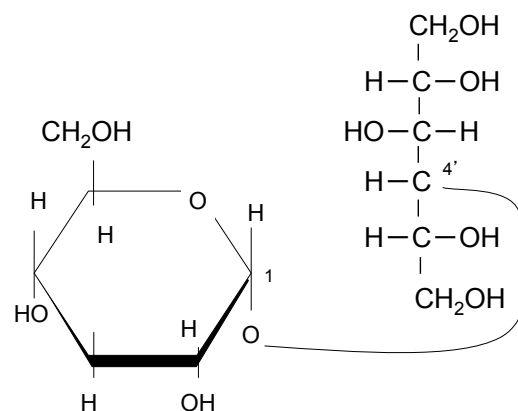**Figure 5**. Structural formulae of sorbitol (D-glucitol, $C_6H_{14}O_6$)

Figure 6. Structural formulae of maltitol (4-O-alpha-D-glucopyranosyl-D-glucitol, $C_{12}H_{24}O_{11}$)
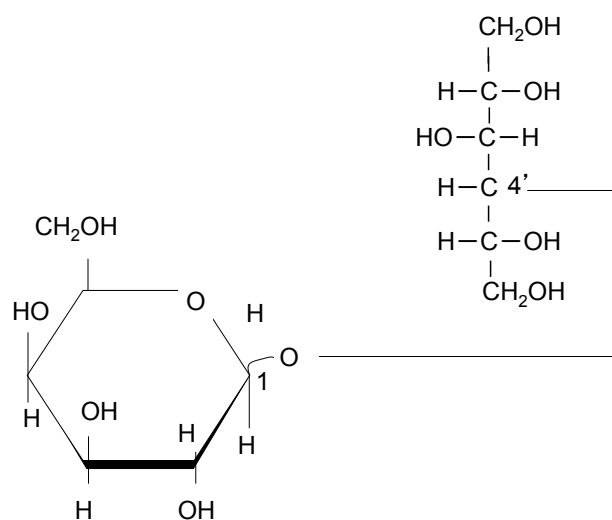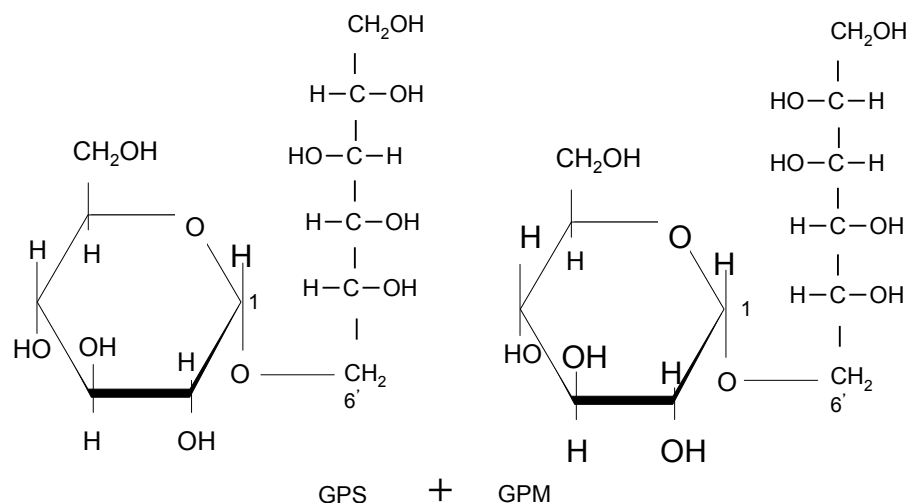

Figure 7. Structural formulae of lactitol (4-O-alpha-D-glactopyranosyl-D-glucitol , $C_{12}H_{24}O_{11}$)

Figure 8. Structural formulae of Palatinit™
(α-D-glucopyranosyl-1,6-sorbitol ($C_{12}H_{24}O_{11}$) and α-D-glucopyranosyl-1,6-mannitol ($C_{12}H_{24}O_{11}$))

Several reports[83-86] have demonstrated that lactitol is non-cariogenic in nature. It is not easily metabolised by acidogenic and polysaccharide-forming oral micro-organisms[83]. It has been found to have extremely low enamel-demineralising activity. The caries scores of lactitol-fed rats in a laboratory experiment were found to be significantly reduced and at the same low level as in laboratory rats on a xylitol regimen[84,85]. Its enamel-demineralising potential has been found to be low *in vivo*, and acid production and dental plaque formation from lactitol in man have been found to be substantially lower than those of sucrose[86].

Palatinit™ <α-D-glucopyranosyl-1,6-sorbitol ($C_{12}H_{24}O_{11}$) and α-D-glucopyranosyl-1,6-mannitol ($C_{12}H_{24}O_{11}$)>

Palatinit™ is obtained by the dehydrogenation of pal-atinose. It is virtually an equimolar mixture of glucop-yranosyl-1,6-sorbitol and glucopyranosyl-1,6-mannitol (*Figure 8*). The sweetness of Palatinit™ is 45% that of sucrose, and the quality of its sweetness resembles that of sucrose. The majority of ingested palatinit reaches the large intestine, where it is fermented to organic acid by enterobacteria and subsequently absorbed. The available energy value is 2kcal/g.

The results of several studies[87,88] suggest that Pal-atinit™ is non-cariogenic in nature. In an experimental caries study using the rat model, caries scores were found to be significantly lower in those rats fed Pal-atinit™ compared with rats fed sucrose and lactose[87]. Moreover, *S.mutans* strains were unable to produce ex-tra-cellular polysaccharide or notable amounts of acid from palatinit[87].

High-intensity sweeteners

These are also used to replace sugars in tabletop sugar, foods, and drinks. In using table sugar, intensive sweeten-ers are added to a bulk non-digestible polysaccharide[89].

Stevia sweetener (Stevioside, Rebaudioside)

This sweetener is extracted from the leaf of stevia (*Compositae*) (*Stevia rebaudiana Bertoni*), which is harvested in the highlands of Paraguay and other parts of South America, and its main components are steviosides. Three types of stevia sweeteners exist. The regular product, consisting mainly of a stevioside (*Figure 9*), the Reva A , consisting mainly of rebaudioside A (*Figure 10*), and the sugar metastasis product. In the regular product, the content ratio of stevioside to rebaudioside ranges from 7:3 to 8:2, while in the Reva A this ratio is about 1:3. Since rebaudioside has a very sweet taste, the qual-ity of sweetness of Reva A is higher than that of the regular product.

The degree of sweetness of stevia is between 150 and 300 times that of sucrose. The majority of the ingested stevia sweetener is utilised by enterobacteria, and the remainder is excreted in the stools. The available energy value is 0 kcal/g.

Results from several studies[90,91] have shown stevia sweeteners to be non-cariogenic. In animal caries ex-periments, significant differences were found in the sulcal caries scores and *S. sobrinus* counts between the sucrose group and the stevia sweeteners group. There were no significant differences between the stevioside and rebaudioside A. This study concluded that neither stevioside nor rebaudioside A is cariogenic[90].

Aspartame <N-L-α-Aspartyl-L-phenylalanine methyl ester, $C_{14}H_{18}N_2O_5$>

Aspartame is a dipeptide ester in which aspartic acid is bound at the N-terminal of phenylalanine (*Figure 11*). It is an odourless white crystalline powder with a refresh-ing sweet taste, and in a 4% aqueous solution aspartame is about 160 times sweeter than sucrose.

Although the quality of taste of aspartame is not as 'mellow' as that of sucrose, it resembles that of sorbitol
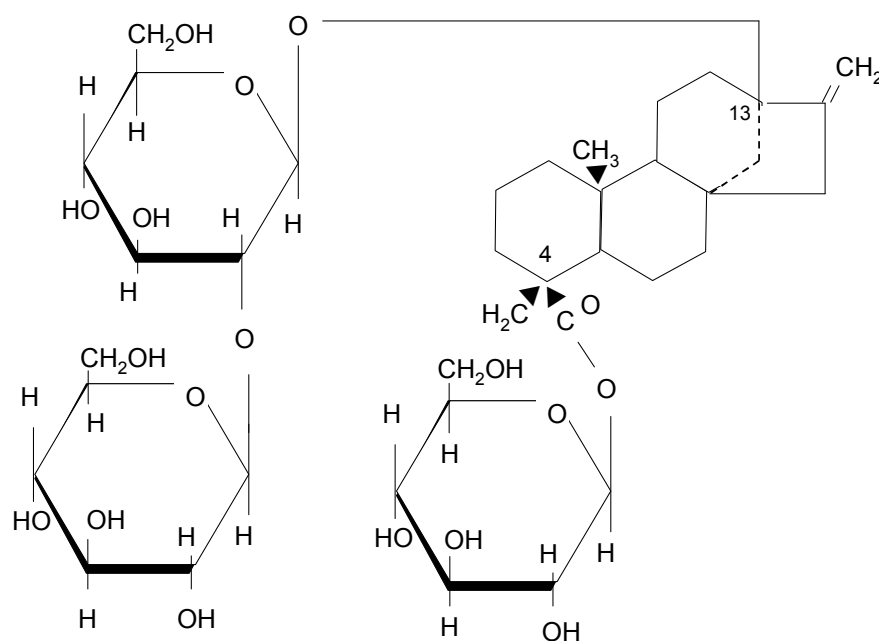
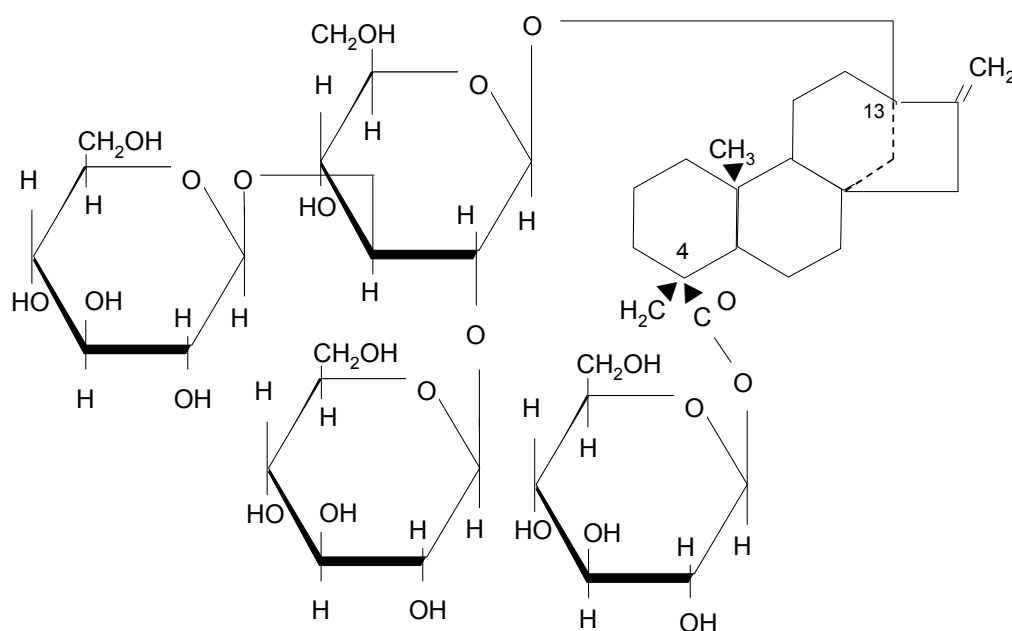**Figure 9.** Structural formulae of stevioside

Figure 10. Structural formulae of rebaudioside A

and is less bitter and stringent than that of stevioside. Aspartame is stable in a powder state at lower temperatures, but polymerisation occurs at temperatures exceeding 100ºC. It is most stable at pH 4, and at this pH even heating at 100ºC for 60 minutes in an aqueous solution results in minimal decomposition, compared with the same heating conditions at pH 6 when 90% or more will be decomposed. The available energy value is 4kcal/g. However, since only a small amount is routinely used in food, the calorific value is negligible.

Several studies have reported that aspartame is non-cariogenic[92-94]. Moreover, in a rat-caries experiment[95],

colonisation by *S.sobrinus* was negligible in those fed aspartame and there was no caries development, while rats fed sucrose plus aspartame had significantly lower caries than those fed the same amounts of sucrose. The authors concluded that aspartame is non-cariogenic, or 'anticariogenic'.

Thaumatin

Thaumatin is a mixture of intensely sweet proteins (thaumatins) extracted with water from the arils of the fruit of the West African perennial plant *Thaumatococcus daniellii*. The thaumatins have a normal complement of
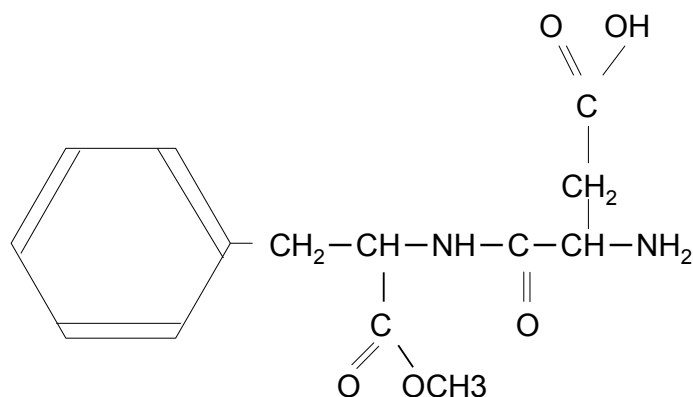
Figure 11. Structural formulae of aspartame
(*N*-L-α-Aspartyl-L-phenylalaninemethyl ester, $C_{14}H_{18}N_2O_5$)

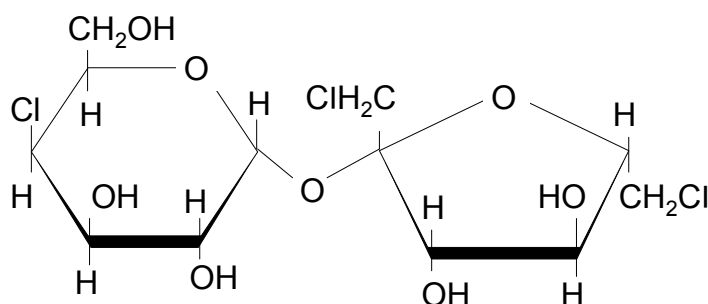**Figure 12.** Structural formulae of sucralose (trichlorogalactosucrose, $C_{12}H_{19}Cl_3O_8$)
(1,6-dichloro-1,6-dideoxy-beta-D-fructofuranosyl-4-chloro-4-deoxy-alpha-D-galactopyranoside)

amino acids, except that histidine is not present. The molecular weights of the thaumatins are approximately 22,000. It is 2,000 times as sweet as sucrose. Although it has been confirmed that mutans streptococci does not liberate acid or insoluble glucan from thaumarin[96], there have been no other studies on anti-ariogenic nature.

Monellin

Monellin is a sweet protein extracted from African serendipity berries, *Dioscoreophyllum cumminsii*. This protein has two polypeptide chains of 45 and 50 amino acids and is about 70,000 times sweeter than sucrose. The sweet sensation persists in the mouth for an unusual length of time. Although monellin had no growth activity of cariogenic bacteria[97], there have been no other studies on anti-cariogenic nature.

Sucralose (trichlorogalactosucrose) <1,6-dichloro-1,6-dideoxy-beta-D-fructofuranosyl-4- chloro-4-deoxy-alpha-D-galactopyranoside>

Sucralose is chemically synthesised from sucrose. It is a sucrose molecule in which three of the -OH groups have been replaced by chlorine (*Figure 12*). Sucralose is relatively stable at high temperatures in aqueous solution. It is absorbed in part and subsequently excreted through the kidneys. It has no nutritional value and is non-caloric. Sucralose is 600 times sweeter than sucrose

and has been approved for use in a number of food products.

Results from several studies[98,99] have shown sucralose to be non-cariogenic. In desalivated rats infected with *S.sobrinus* and *Actinomyces viscosus*, sucralose, sorbitol and aspartame in the drinking water induced little or no caries development[99].

How do sucrose substitutes help to prevent dental caries?

The use of sucrose substitutes in sweets is believed to have contributed in part to the decline in the prevalence of dental caries in industrialised countries. Marthaler *et al.*[16] have addressed this issue in Switzerland, where many sweets containing sucrose substitutes have been commercially available since 1970. The results of their study suggested that sucrose substitutes are one of the factors that have contributed to the decline in the prevalence of dental caries in Switzerland since the 1980s. However, there is no evidence to indicate that sweets containing sucrose substitutes are as effective as fluoride in reducing levels of dental caries.

From the results of controlled human studies, the dental caries preventive effect has been observed in cases where regular sweeteners in foods are consistently replaced with a sucrose substitute[3] or when chewing

gum containing a sucrose substitute is regularly taken after each meal[4]. Therefore, it seems unlikely that occasional eating of sweets containing a sucrose substitute will play a significant role in preventing dental caries.

Most of the sucrose substitutes discussed above are considered non-cariogenic. Furthermore, many reports of *in vitro* and *in vivo* studies on specific characteristics such as the anticariogenicity of sucrose substitutes have been published. Their anticariogenic effects include:

- Inhibition of insoluble glucan synthesis from sucrose by mutans streptococci[36,38]
- Decrease in mutans streptococci numbers in whole saliva and plaque[3,65,68-69]
- Increase in the buffering capacity and pH of dental plaque[3,64,65,67]
- Interference with enamel demineralisation and an increase in enamel remineralisation[3,21,45-54].

The claim for anticariogenicity has mainly been based on the results of human studies carried out using xylitol-containing chewing gum. However, these effects are not unique to xylitol[32-34,42,54]. In fact, the inhibitory effect of xylitol on the growth of mutans streptococci is rather weak, and the remineralisation activity is common to all sugar alcohols. Regarding the active non-cariogenic nature of xylitol chewing gum, the role of the enhancement of salivary factors must also be emphasised in addition to the role of the xylitol itself[100-104]. Recently, van Loveren examined clinical studies on caries preventive and therapeutic effects of sugar alcohols. He concluded that caries preventive effects of sugar alcohol-containing gums and candies seem to be based on stimulation of salivary flow and there was no evidence for a caries-preventive effect of xylitol[105]. The advantages of xylitol as a substitute sweetener are that its sweetness is similar to that of sucrose and that it provides a cooling sensation in the mouth because of its high solubility. Consequently, this property can be used to enhance marketing potential and improve the dietary behaviour of children, adults and the elderly.

The various sucrose substitutes have different characteristics, which can each be harnessed if used in combination. For example, adding aspartame or stevioside to maltitol and xylitol has been recommended, as has using a combination of palatinose and xylitol[40]. However, adding xylitol to fermentable sugars, such as sucrose, should be avoided.

A number of chewing gums have been developed that promote remineralisation of enamel, and some of them are now being marketed. These chewing gums contain sucrose substitutes in combination with a calcifying agent, such as calcium phosphate[102], phosphopeptide amorphous calcium phosphate complexes (CPP-ACP)[106-109], or funoran[110-112]. More of these chewing gums with their added benefits will be developed and thus will assist in promoting dental health.

It should also be kept in mind that the quantity of sucrose substitutes used in preserved foods other than sweets is rather high in some communities. Sugar alcohols are a particular case in point. A high intake of sugar alcohol causes intestinal disorder.

Using sucrose substitutes to promote oral health

Using sucrose substitutes in all sweets would be an effective public health measure, but this is not a realistic option[101]. Instead, we need to consider how to use sucrose substitutes or non-cariogenic sweets to promote oral health. Each of the sucrose substitutes has particular characteristics that should be utilised so that the requirements of specific individuals are met.

The prevalence of dental caries in children is declining, but children at high risk of developing dental caries are still an important public health concern. Dental caries has an age-specific characteristic in that ageing populations are also at risk of root caries. Practical methods of evaluating an individual's dental caries risk have been established and these methods can be applied in general dental clinics and community health centres. The use of non-cariogenic sweets can be recommended by professionals in these clinical settings as an important adjunct to reducing dental caries risk in individuals[102]. To ensure success, a greater variety of sweets is required and new sucrose substitutes of nutritional value should also be developed.

Many medicines have been found to have the side effect of producing a dry mouth (xerostomia), and prolonged use of such drugs contributes to an increased risk of dental caries. Using non-cariogenic chewing gum to promote salivation would clearly be beneficial in these cases[102].

Industrialised countries commonly use a labelling system for listing the ingredients of processed food to enable the consumer to select foods in keeping with their personal health concerns. For example, in Japan a government-sanctioned mark is used to indicate the specific function of the food product in disease prevention[113]. In the case of dental caries, labels such as 'These sweets do not cause dental decay' and 'These sweets promote remineralisation of dental enamel' are displayed. These labels can play a significant role in informing the consumer dental caries prevention and will certainly become more widespread in the future.

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