2 Sweeteners

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2.1 Introduction

From the 1950s onwards, there have been concerns about the effect of diet upon health. High carbohydrate intake, especially sugar, was implicated in the so-called 'diseases of affluence', including cardiovascular disease, obesity, diabetes mellitus and other metabolic disorders. The role of sucrose in the incidence of dental caries has also been of great concern. The United Kingdom NACNE (NACNE, 1983) and COMA (COMA, 1984 and 1989) reports recommended certain dietary changes including significant reductions in the consumption of sugar. While the contribution of dietary sugar to obesity and other diseases was inconclusive, a link between sugar consumption and the incidence of dental caries was in evidence. The concerns reflected in these and other reports have played a major role in the commercial development of a whole range of sucrose substitutes, otherwise known as sweeteners.

The properties sought in a sucrose replacement may be summarised as:

1. The same taste and functional characteristics as sucrose.
2. Low caloric density on a sweetness equivalency basis.
3. Non-cariogenicity.
4. Metabolised normally or excreted unchanged.
5. No allergenic, mutagenic, carcinogenic or other toxic effects in the body.
6. Chemical and thermal stability.
7. Compatibility with other food ingredients.
8. Economically competitive with existing sweeteners.

Sweeteners may be nutritive, as are the hydrogenated sugars, also known as sugar alcohols or polyols, or non-nutritive, as are the intense sweeteners. They can be synthesised or extracted from natural sources. Intense sweeteners contribute no bulk, viscosity or texture to foods and beverages, and must be mixed with nutritive sweeteners or some other bulking agent when these properties are required.

The development of a wide range of sweeteners has advantages for the food industry. Because of the idiosyncratic properties of individual sweeteners, one may be better suited to a specific application than others.

Furthermore, there are possibilities for combining two or more sweeteners in a product. Improved safety is one benefit of mixtures, since the required quantity of each component sweetener is then reduced. In addition, mixtures of sweeteners provide the developer with many more opportunities, than with single sweeteners, for optimising such features as the quality and stability of the taste profile of the final product. Mixtures of sweeteners can be tailored to the product, by their mutual complementation and compensation of characteristics. For example, saccharin may be combined with aspartame, resulting in a mixture that has greater stability then aspartame and masks the after-taste of saccharin, with the bonus of synergism for sweetness. In products where bulking and texturing is required, the calorific value can be reduced, while sweetness is maintained, by combining a sugar alcohol with an intense sweetener. The lingering, menthol-like sweet taste of thaumatin may be desirable for oral-care products to achieve a long-lasting fresh taste in the mouth, and the delayed onset of thaumatin-taste can be compensated for by its combination with another sweetener providing instant sweetness.

The ideal replacement for sucrose has yet to be found, and the volume of worldwide applications for patent registrations of sweet substances is testimony to the continuing quest to achieve this goal. Few, however, survive the rigours and expense of the full gamut of safety evaluations now required for entry into the market place.

The sweeteners discussed here are the polyols, including sorbitol, mannitol, xylitol, maltitol, lactitol, isomalt, and Lycasin®, a hydrogenated glucose syrup; the intense sweeteners, including saccharin, cyclamate, aspartame, acesulfame-K, thaumatin, stevioside and neohesperadin dihydrochalcone (NHDC); and some new sweeteners currently being developed, including sucralose and RTI-001. The sensory and physical properties of these sweeteners are detailed in Tables 2.1–2.3. Information of the general background of individual, or groups, of sweeteners, together with details of mixtures, health and safety, regulations and applications, is provided in the text.

2.2 Polyols

2.2.1 *General*

The polyol sweeteners are sugar alcohols produced by the hydrogenation of sugars and syrups, with the aid of a catalyst, usually Raney nickel. These include *sorbitol*, *mannitol*, *xylitol*, *maltitol* and *lactitol*, derived from glucose, mannose, xylose, maltose, and lactose, respectively; *isomalt*, an equimolar mixture of glucopyranosyl-sorbitol and glucopyranosyl-mannitol resulting from the hydrogenation of isomaltulose (also known as palatinose); and

hydrogenated glucose syrups (*HGS*), such as *Lycasin*® *80/55*, derived from starch hydrolysates.

The first hydrogenated sugar to have been manufactured was *sorbitol* in the 1930s. This was followed by *mannitol*, *HGS* including *Lycasin*®, and *xylitol* in the early 1970s. *Isomalt*, *maltitol* and *lactitol* were more recent developments.

A major sorbitol producer, Roquette Frères of France, acquired the patent rights to *Lycasin*® in 1975. *Isomalt* is marketed by Suddeutsche Zucher AG, West Germany, as *Palatinit*®, and by Tate and Lyle plc, UK, as *Lylose*®. *Lactitol dihydrate* was developed by CC Biochem of The Netherlands, and is sold exclusively by Philpot Dairy Products in the UK under the brand name *Lacty*® (Anon, 1989d). *Xylitol* is marketed by Finnsugar Xyrofin. *Maltitol* is available as *Malbit*®, with <90% maltitol and >5% maltotriitol, and Roquettes Frères applied for a French patent in 1987 for compressible *maltitol* (>85%) powder for use as a sweetener (Anon, 1987a).

2.2.2 *Properties*

Physical. Sugar alcohols are functionally similar to sucrose, and are bulking agents. *Sorbitol*, *mannitol*, *xylitol* are naturally occurring, like sucrose, thus promoting consumer appeal. There are both technical and physiological benefits of these conversions. The technical benefits include increased chemical stability and affinity for water, without altering the sweetening power, and a reduced tendency to crystallise. The physiological benefits are that the sugar alcohols have low cariogenicity. They are suitable for inclusion in products for diabetics because their metabolism is insulin-independent, and some are low in energy because of their malabsorption in the intestine (Hough, 1979). *Lycasin* was developed as a product to replace sucrose that was not harmful to teeth.

There are specific properties of the sugar alcohols (summarised in Table 2.1) that distinguish them apart, and bestow upon them particular advantages and disadvantages in their applications. For instance, *sorbitol* has special properties of high viscosity, humectancy and crystal form. It is readily soluble in water, but virtually insoluble in all organic solvents, except alcohol (Hough, 1979). *Mannitol* has low solubility in water, but is useful as an anti-adhesion agent, inhibiting the crystallisation of other polyalcohols in the manufacture of chewing gum (Sicard and Leroy, 1983). *Maltitol* is highly hygroscopic, inhibiting crystallisation; has excellent heat stability, with no loss of colour during boiling (Fabry, 1987); and has low fermentability by common moulds and bacteria (Grenby, 1983). *Lactitol* has good solubility in water, that increases with temperature. At 25°C, 150 g of *lactitol monohydrate* or 140 g of *lactitol dihydrate* (*Lacty*®) will dissolve in 100 ml water. Its white, crystalline, solid form melts at about 120°C for the *lactitol*

monohydrate, and at about 75°C for the *dihydrate*, and is partly converted into lactitan, *sorbitol* and lower polyols when heated at 179–240°C (den Uyl, 1987). *Lactitol* has some useful parallels with sucrose. Its viscosity in solution is equal to that of sucrose, weight for weight, and it lowers the freezing points of solutions, in the same way as sucrose – important in making ice-cream. Decomposition is a function of temperature and acidity, but *lactitol solutions* have excellent storage stability in the pH range 3.0–7.5 and at temperatures of up to 60°C. While no detectable decomposition of 10% *lactitol solutions* was observed under these conditions after 1 month, there was 15% decomposition at pH 3.0 after 2 months, but none at 105°C at pH 12.0 (den Uyl, 1987).

Lycasin® 80/55 is a clear, colourless, odourless syrup, also available in a powder form, that is very stable, chemically inert, and has technical properties that permit its replacement of sucrose in many food products, especially confectionery.

Isomalt is white and odourless, with a crystalline form. Its solubility in water is a function of temperature, with about 25% solubility at 20°C and 55% at 60°C. Solubility decreases linearly, though, with the addition of alcohol (Strater, 1986). *Isomalt* is highly stable with respect to chemical and microbial breakdown. It has no Maillard reaction so that browning inhibitors are unnecessary. *Isomalt* melts within the range 145–150°C, and changes colour only slightly when held at 170°C for 60 minutes. There are no further colour changes after the first hour, in contrast to sucrose solutions, which suffer exponential increases in colour (Strater, 1986). Its viscosity in aqueous solution is comparable to that of sucrose solutions.

Sensory. Xylitol has about the same sweetness as sucrose, weight for weight, with slight variations due to conditions of temperature, pH and concentration (Anon, 1986a). The other sugar alcohols are less sweet (Table 2.3) and need supplementation with intense sweeteners to be comparable to sucrose. Reports of the sweetness of *Lycasin® 80/55* vary between 55% and 75% that of sucrose.

Sugar alcohols add texture and mouthfeel properties to foods and drinks since they are bulking agents. Many of the sugar alcohols, *xylitol* and *sorbitol* in particular, impart a cooling sensation in the mouth because they absorb heat as they dissolve. Isomalt, however, does not possess this characteristic. All have pleasant, sweet taste profiles with no after-taste.

2.2.3 *Mixtures*

Sugarless chewing gums typically contain *sorbitol* and/or *mannitol* as sugar substitutes, and the reduced sweetness is supplemented with the addition of intense sweeteners. Saccharin is commonly used, because sufficiently small concentrations are needed for the saccharin taste limitation to be imperceptible.

tible. *Sorbitol* is also combined with intense sweeteners in products for diabetics.

Xylitol is used, especially in Europe, alone or with other polyols or polydextrose in sugarless confectionery products. Some advantages of the bulking agent, polydexterose, are that it has low laxative properties, low calorific value (1 kcal g^{-1}) and is tolerated by diabetics. It is, however, low in sweetness.

It is claimed that no intense sweeteners are required to supplement *Malbit*® in order to obtain the sweetness and flavour release properties close to those of sucrose-sweetened products (Fabry, 1987). It is often desirable, by contrast, that the sweetness of *lactitol*-containing products be increased, preferably by the addition of aspartame or acesulfame-K. A 10% *lactitol solution* containing 0.03% aspartame or acesulfame-K has the equivalent sweetness of a 10% sucrose solution (den Uyl, 1987).

Isomalt is synergistic with other sugar alcohols, such as *sorbitol*, *xylitol* and *HGS*, and with intense sweeteners, such as saccharin and aspartame. Metallic after-tastes of intense sweeteners are masked in such mixtures. *Isomalt* can also be mixed with the low-calorie bulking agent, polydextrose, in the production of calorie-reduced foods (Mackay, 1987).

Lysasin® has an agreeable sweet taste that needs no supplementation in confectionery with intense sweeteners (Sicard and Leroy, 1983). However, it may be added to products with other polyols, such as *sorbitol* and *isomalt*, as a crystallisation inhibitor.

2.2.4 *Health and safety*

The most attractive feature of the polyol sweeteners is that they are suitable as sugar substitutes for caries prevention. *Xylitol* is outstanding in this regard. Long-term field trials have been carried out, such as the Turku studies in Finland in the 1970s, and those commissioned by the WHO in the mid-1980s with caries-prone children in Hungary and French Polynesia. The results clearly demonstrated the caries inhibiting effect of *xylitol* when consumed in small quantities (14–20 g) as an addition to the daily diet. Subsequent studies have confirmed the protective effect of *xylitol*-sweetened chewing gum, although the mechanism by which *xylitol* inhibits caries development is unknown (Pepper and Olinger, 1988).

The close structural similarity between many bulk sweeteners and normal carbohydrates has led to limited applications for toxicological assessments. The absence of any adverse effects, though, i.e. complete food safety, has been demonstrated for *xylitol*, and for *isomalt*, the components of which are found in the body anyway (Ziesenitz and Siebert, 1987). However, a limitation of the polyols is their laxative effect at high doses, and warning labels on products are required in some countries.

Sorbitol has been used since the 1920s for sweetening foods for diabetics,

since its metabolism causes only an insignificant rise in blood glucose. Similarly, *xylitol* (Sicard, 1982), *lactitol* (den Uyl, 1987) and *isomalt* (Strater, 1986) are metabolised with no significant changes of blood glucose and insulin, and so are suitable for inclusion in the diets of diabetics. *Mannitol* is less desirable for diabetics because of its low laxative threshold (Table 2.3). *HGS* and *maltitol* are also disadvantageous because glucose is a breakdown product in the gut (Dwivedi, 1987).

The malabsorption of some of the polyols, such as *lactitol*, gives rise to a beneficial physiological side effect. Such unabsorbed polyols act as dietary fibre, being fermented by the microflora of the large intestine and contributing to faecal mass (Booy, 1987).

A limitation of sugar alcohols is their laxative effect when consumed in large doses. However, the EEC Scientific Committee on Food (SCF) advised that 20 g per person per day of polyols is unlikely to cause undesirable laxative symptoms (Anon, 1984). In some countries, product labels may be required to carry an appropriate warning, depending upon the amounts involved.

2.2.5 *Regulations*

Isomalt, *mannitol*, *sorbitol*, *sorbitol syrup*, *xylitol* and *hydrogenated glucose syrups* were among the 12 sweeteners listed as permissible for food use in the UK (Statutory Instruments, 1983). *Lactitol* was added in 1988 (Sweeteners in Foods (Scotland) Amendment Regs., 1988).

Palatinit Isomalt was under examination earlier this year (Anon, 1989c) by the National Health and Medical Research Council for inclusion in Australian Food Standards.

Xylitol is permitted in more than 40 countries for use in foods and other products, including the EEC, North America and Scandinavia (Anon, 1989d). It was given FDA and WHO/FAO clearance in 1978 for sweetening of Special Dietary Foods, but not GRAS (Generally Recognized As Safe) status. *Sorbitol* and *Lycasin*®, however, have been affirmed as GRAS (Mackay, 1979).

Maltitol is permitted in certain foods in Japan, and HGS in Switzerland, The Netherlands and Scandinavia. These sweeteners are not permitted for food use, though, in the US. *Sorbitol* and *mannitol* are listed as permitted sweeteners or food additives, subject to certain restrictions, in the US, South Africa, UK, Belgium, Denmark, Greece, Spain, France, Germany, Switzerland, Sweden, Japan, Australia and Canada, and *sorbitol* additionally in The Netherlands, Italy, Norway, Finland and Brazil.

JECFA allocated an ADI 'not specified' for *lactitol*, in 1983, and for *isomalt* and *HGS* in 1985, with the additional comment that levels should be appropriate in consideration of the known laxative effect of polyols (Joint FAO/WHO, 1987).

2.2.6 *Applications*

Sugar alcohols are indispensable in products marketed as low in cariogenicity, and for diabetics, when a bulking function is required.

Economics is an important consideration in applications. *Xylitol* is a relatively expensive polyol (Table 2.1; Dwivedi, 1986) but this could be counterbalanced by its wide consumer appeal on account of its dental advantages and its status as a naturally occurring compound. *Mannitol* has also been a very expensive sweetener (Table 2.1; Dwivedi, 1986) because of the purification processes required to separate it from *sorbitol* and other contaminants in its manufacture, but methods of reducing these production costs are being researched. *Mannitol* is mainly used in the crystalline form in sugar-free chewing gum, and also in chewable pharmaceutical products as it is inert (as are other sugar alcohols) to most drug components. Its application in products such as soft drinks, ice-cream and confectionery is restricted by its low solubility.

Sorbitol is an attractive sweetener for manufacturers who wish to make use of its special properties since it needs no special handling. For instance, it is used in fondants, fudges, marshmallows and caramels to retard sucrose crystallisation and thus to retain freshness and flavour. It acts as a humectant and anticaking agent in baked goods. *Sorbitol*, supplemented by an intense sweetener, is used to sweeten diabetic products such as table-top sweeteners, preserves, jellies, and confectionery. It may totally replace sucrose in chocolate and ice-cream for diabetics, although the final products are distinguishable (Hough, 1979).

Xylitol is used mostly as a sweetener in sugarless chewing gum. It also has potential in tableted products such as mints and children's chewable vitamin tablets. This can be in a 50:50 combination with sorbitol (the gamma form of tableting grade is preferred), both milled, blended and compressed. However, this combination suffers from poor flow properties, and the direct compression of *Xylitol DC*, containing not more than 4% *sorbitol* may be preferable. This method, using a force of 20 kN to produce tablets of 15 mm diameter, results in a satisfactory hardness, since the melted *xylitol* recrystallises during overnight storage (Pepper and Olinger, 1988). In chocolate, *xylitol* is a good choice as a substitute for sucrose because of its equi-sweetness, but its high relative cost may be prohibitive. Conching can take place at temperatures of up to 55°C. *Xylitol* is successfully combined with *sorbitol* to provide the syrup phase in fondants, and is exceptionally good with mint and chocolate flavours. Its use in pectin and gelatine jellies produces high-quality products, but, since *xylitol* reduces gel strength, extra gelling agent is required (Pepper and Olinger, 1988).

Maltitol aids moisture retention in baked goods, and is regarded as suitable for carbonated beverages, canned fruits (Hough, 1979) and confectionery, especially gloss coatings (Grenby, 1983). *Malbit*® is available in

both crystalline and liquid forms, with sweetnesses, relative to sucrose, of 0.8–0.9 and 0.6 respectively (Table 2.3). Due to its physiological, organoleptic and technical properties, *Malbit*® can be used in the development of a new generation of health and speciality products, including dietary, diabetic, tooth-protective and slimming products. It has been used in products in Japan for ten years, and is now on the market in some European and Asian countries in dark and milk chocolate, hard-boiled candies, soft caramels, toffees and chewy fruits, fruit pastilles and liquorice gums based on gum arabic, gelatin gums and jellies, chewing gums and bubble gums, chocolate dragees using panning technology, other types of confectionery including sugarless tablets and muesli bars, jams, and ice-cream (Fabry, 1987).

Lactitol can replace sucrose as a sweet-tasting texturising or bulking agent in a variety of applications with equal palatibility and no aftertaste (den Uyl, 1987). According to Philpot Dairy Products, *Lacty*® can be used in bakery products, confectionery, ice-cream, jams and marmalades and table-top sweeteners (Anon, 1989d). Because of its low hygroscopicity, *lactitol* is particularly suitable, in conjunction with its low caloric value, for use as a bulking agent for intense sweeteners in table-top use, and for biscuit making since crispness is maintained. It is also successfully used as a surface dusting for confectionery. *Lactitol* is suitable, also, for inclusion in low-calorie and sugarless products such as chewing gum, fruit gums and pastilles, chocolate, instant beverages and jams. The inclusion in the product of a crystallisation inhibitor, such as *Lycasin*, may be necessary.

Isomalt is a suitable ingredient for confectionery, baking and soft drinks. Its ready crystallisation simplifies the coating of hard-boiled and chewable candies, and can be used to enhance the shelf-life of hygroscopic products. Because of the high percentage of solids dissolved in the aqueous phase, *isomalt* can also be used as a melt for the manufacture of soft caramels, chewing gums and soft candies, probably with the addition of a crystallisation inhibitor, such as *HGS* (Strater, 1986).

Lycasin has the same viscosity, colour and shelf life as ordinary starch syrups, and so can perform the same function in sugar-free products, such as confectionery and jam (Rockstrom, 1980). *Lycasin* is highly hygroscopic due to its *maltitol* content. Because of this characteristic, *Lycasin*® *80/55* is useful in the manufacture of liquid-centre confectionery, and has an anticrystallising effect on other product ingredients, such as *sorbitol* in chewing gum (Sicard, 1982).

2.3 Saccharin

2.3.1 *General*

Saccharin was accidentally discovered in 1879 by Fahlberg and Remsen, and manufactured five years later. It was first used as an antiseptic and preservative, but as a sweetener since 1900. Saccharin is synthesised com-

Table 2.1 Properties of sucrose and polyols

	Sucrose	Sorbitol	Mannitol	Xylitol	Malbit®	Lactitol	Isomalt	Lycasin®
Sensory								
Sweetness intensity	1	0.6	0.6	1	0.6–0.9	0.35	0.45	0.55–0.75
Mouth-cooling effect	None	High	Low	High	Low		None	
Physiological								
Energy (kcal g^{-1})	4	4	<4	<4	2	2	2	Not studied
Cariogenic potential	High	Low	Low	None	None	None	None	Low
Suitability for diabetics	None	High	Low	High	Low	High	High	Low
Laxative at (g day^{-1})	No effect	50–75	20	50–70	50	70–80	20–30	30–50
Physical								
Molecular weight	42	182	182	152	344.47 (maltitol)	362 monohydrate, 380 dihydrate	368	340+
Hygroscopicity	High	High (solutions) Low (powder)	Low	High	High	Low	Low	High
Browning reaction	Yes	No	No	No	No	No	No	No
Solubility in water (g (100 ml)$^{-1}$) room temp.	High (66)	High (75)	Low (18)	High (63)	Medium	High (149 monohydrate, 140 dihydrate at 25°C)	Low (25)	Supplied as syrup
Melting point		96–97	165–168	93–94.5	135–140	115–125 monohydrate, 70–80 dihydrate	145–150	
Stability	Stable in neutral pH	Stable to heat, chemically unreactive	Chemically stable	Chemically stable	Chemically and thermally stable	Solutions: good at pH 3.0–7.5 and at temps. <60°C for 1 month	Resistant to chemical and microbial breakdown	Stable, chemically inert
Other								
Price ratio (1986)	1	1.4 liquid 2.3 crystalline	4.0 crystalline	10.0 crystalline				
ADI mg (kg body weight)$^{-1}$		'None specified'		'None specified'		'Not specified'	'Not specified'	

Sources: Sicard and Leroy (1983); von Rymon Lipinski (1987); Grenby (1983); Pepper and Olinger (1988); den Uyl (1987); Hough (1979); Ziesenitz and Siebert (1987); Dodson and Pepper (1985); Sicard (1982); Anon (1988); Joint FAO/WHO (1987); Booy (1987); Fabry (1987); Dwivedi (1986); von Hertzen and Lindqvist (1980).

mercially from toluene, and has a chemical formula of $C_7H_5NO_3S$. It is usually available as the sodium salt and sometimes as the calcium salt. Other saccharin salts are not commercially available, although reputedly sweet (Walter and Mitchell, 1986).

Saccharin is the most widely used sugar substitute in the world, probably because of its high stability and low cost, and the only available intense sweetener in some countries for many years. It has been called the 'pioneer' sweetener, paving the way for a variety of low-calorie products (Bakal, 1987), but has the disadvantage of a bitter, metallic after-taste.

2.3.2 *Mixtures*

Mixtures with saccharin have been made for three reasons: to mask the unpleasant taste characteristics of saccharin; to provide bulk as well as sweetness; and to take advantage of synergy for sweetness (Table 2.3).

Many mixtures, thought to improve the taste of saccharin, have been patented. These have included combinations with other sweeteners, notably cyclamates and aspartame, as well as with such ingredients as cream of tartar, glucono-δ-lactone, sodium gluconate, glycols, gentian root, maltol, pectin, lemon flavour, ribonucleotides and adipic, aldohexuronic and citric acids. For example, cyclamate/saccharin combinations at a ratio of about 3:1 were most successful, when both were permitted sweeteners, with high consumer acceptance and providing sugar-like sweetness in beverages. Since cyclamate was banned in the US in 1969, it has been replaced by calcium chloride in combination with cornstarch hydrolysate, lactose, sucrose, tartrates, and fructose with gluconate salts in combination with saccharin (Bakal, 1983; Walter and Mitchell, 1986).

Saccharin is synergistic with cyclamate and with aspartame.

2.3.3 *Health and safety*

Saccharin is not metabolised in the body, but is excreted unchanged. Although bladder tumours have been associated with saccharin intake in rats, extensive research on human populations has established no such association. Research included three major studies with diabetics, who consume greater amounts of saccharin than the general public, but no increased risk of cancer was in evidence with this group (Walter and Mitchell, 1986).

Saccharin has been assigned an ADI of 2.5 mg kg^{-1} of body weight. However, there are fears presently that this level may be exceeded by some sectors of the population, and the Ministry of Agriculture, Fisheries and Food (MAFF) in the UK have called for an investigation (Anon, 1989b).

Recent research indicates that saccharin has anticariogenic properties, rather than non-cariogenic properties as previously supposed (Linke, 1987).

2.3.4 *Regulations*

Saccharin is used in more than 80 countries, but its approval in the US has had a stormy history. In 1977 the FDA proposed to ban it because of the discovery of bladder tumours in rats fed on high doses of saccharin. However the ban was suspended due to its extreme unpopularity, while further investigations were completed. In July 1987, the Judicial Review of the Code of Federal Regulation with regard to Food Additives (CFR, 1989) extended the moratorium on saccharin until 1 May 1992. Despite the caution of the FDA, reviews by other regulatory bodies have approved the use of saccharin. These have been the Food Additives and Contaminants Committee (FACC) of Great Britain in 1982, the Joint Expert Committee on Food Additives (JECFA) in 1984, and the Scientific Committee for Food of the Commission of the European Economic Communities (EEC) in 1984 (Walter and Mitchell, 1986).

2.3.5 *Applications*

Saccharin has a wide range of applications due to its high stability, nil calorific value, non-cariogenicity, and its low cost. A prime asset of saccharin is its high stability in a wide range of products even under extreme conditions of processing. It is the only approved sweetener which can withstand heating, baking and high-acid media (Bakal, 1987), and is one-twentieth the price of sugar in terms of sweetness equivalency.

It has been used in soft drinks, candies and preserves, salad dressings, low-calorie gelatine desserts, and combined with bulk sweeteners in baking for sugar-reduced products. It has been produced as a variety of table-top preparations either as a single sweetener, in tablet and liquid form, or in combination with other sweeteners, and incorporated into chewing gum on its own or combined with sorbitol or aspartame. Saccharin is also a popular choice in oral-hygiene products such as toothpaste and mouthwashes.

The future prospects for saccharin in the market place are unclear because of consumer concerns about its safety and because of the present availability of alternative sweeteners such as aspartame and acesulfame-K. Its survival may be restricted largely to combinations with other sweeteners.

2.4 Cyclamate

2.4.1 *General*

Cyclamate (N-cyclohexyl-sulphamic acid) was discovered in 1937 by Michael Sveda of Abbott Laboratories, Chicago. It was used as a sweetener from the mid-1950s, becoming the dominant artificial sweetener in the 1960s

in the form of its sodium and calcium salts. It was the major factor in launching the diet segment of the food and beverage industries. However, it lost GRAS status in 1969, was banned in 1970 in the USA, and soon after in the UK and other countries. Its ban resulted in the deterioration of taste profiles of soft drinks, in particular, and an incentive to develop new sweeteners. Cyclamate is still permitted in some applications, however, in some countries including Spain, Germany and Switzerland (Kasperson and Primack, 1986).

2.4.2 *Mixtures*

Cyclamate has only one tenth the sweetness of the equivalent weight of saccharin. However, it was found in the 1950s that their combination in the ratio 10:1, on a sweetness equivalency basis, produced a most desirable sweetness (Miller, 1987). Cyclamate masked the after-taste of saccharin, and the low sweetness of cyclamate was boosted by saccharin and by the synergy of their mixture (Table 2.3). This combination became the first commercial multiple sweetener, and was used in the 1960s in diet soft drinks, table-top sweeteners, low-calorie frozen desserts, salad dressings, jams, jellies, and other products (Gelardi, 1987). It remains a widely used sweetener mixture, even though cyclamate is now banned in some countries (Lindley, in press).

Combinations of cyclamate with aspartame, and with aspartame and saccharin together, have also been found to improve stability and to give good taste profiles in table-top sweeteners, diet soft drinks, dry beverage mixes and chewing gum (Gelardi, 1987). Cyclamate is also synergistic with sucrose (Table 2.3).

2.4.3 *Health and safety*

Cyclamate has no calories and is non-cariogenic, but there have been fears concerning its toxicity. Early studies concluded that the compound was poorly absorbed in the gut, and excreted unchanged, thereby excluding any undesirable metabolic effects or by-products. However, later evidence contested this finding. In an experiment with rats (Price *et al.*, 1969), fed daily for a lifetime on high doses of cyclamate and saccharin in a 10:1 ratio, it was found that cyclamate was metabolised to a product called cyclohexylamine, and this metabolite became implicated in the occurrence of bladder tumours appearing after two years. Although the evidence against cyclamate was not 100% conclusive, there were also fears about other effects on genetic material, leading to its withdrawal in some countries.

2.4.4 *Regulations*

Cyclamate was approved as a food additive by the FDA in 1949, and achieved GRAS status in 1958. However, it was banned in the US with effect

from 1970 (Federal Register, 1969) because of its association with tumours in rats. Bans in the UK, Canada and Japan followed, while restrictions were made in several European countries.

Abbott Laboratories petitioned the FDA in 1973 and in 1980 to reapprove cyclamate on account of the numerous studies that failed to confirm the carcinogenicity of cyclamate or its metabolite. In 1985, the National Academy of Sciences (NAS) supported the conclusion of the 1984 Cancer Assessment Committee that cyclamate is not a carcinogen. In 1986 the FDA arranged further toxicological tests of food additives, including cyclamate. However, the ban on cyclamate and its derivatives for food uses was reaffirmed in April 1989 (CFR, 1989).

In 1982, a review of sweeteners in the UK recommended a continued prohibition of cyclamate due to its unknown effects on man, but JECFA, in the same year, replaced a temporary approval of cyclamate with a full one and an increased ADI of 11 mg kg^{-1} of body weight (Higginbotham, 1983).

2.4.5 *Applications*

Cyclamate has the benefits of good taste and low cost but, where it is permitted, the quantities required on account of its low sweetness are likely to be in excess of ADI amounts. Further applications, then, are likely to be in mixtures of sweeteners.

2.5 Aspartame

2.5.1 *General*

The sweet taste of the compound, aspartame, was discovered accidentally in 1965 by James Schlatter, while synthesising a product for ulcer therapy. Aspartame is a dipeptide methyl ester, composed of the two amino acids, phenylalanine and aspartic acid. It is marketed by G.D. Searle as Nutrasweet®, as Equal® and as a tablet sweetener called Canderel®, and by the Holland Sweetener Company of The Netherlands as Sanecta®. It has a very agreeable sweet taste but is unstable under certain conditions (Table 2.2).

2.5.2 *Mixtures*

Mixing aspartame with other sweeteners has the advantages over its use as a single sweetener of improving processing and shelf stability, while producing a balanced taste. Furthermore, mixtures of aspartame with acesulfame-K, or with sodium saccharin, sodium cyclamate, glucose or sucrose, are synergistic (Table 2.3), having the added advantage of cost reduction.

Table 2.2 Properties of intense sweeteners

	Saccharin	Cyclamate	Aspartame	Acesulfame-K
Source	Synthetic	Synthetic	Synthetic	Synthetic
Discovery	1879	1937	1965	1967
Appearance	White, crystalline powder	White, crystalline powder	White, crystalline powder	White, crystalline powder
Molecular weight	205 Na salt		294	201
Solubility (room temp.)	82% Na salt 67% Ca salt	Na and Ca salts readily soluble in water	38% water; 0.4% ethanol at 25°C; not soluble in fats and oils	31% water (100% at 100°C); 0.1% ethanol; >30% dimethylsulphoxide
Stability: pH	Stable in range 2–7	Stable in range 2–7 at normal process temperatures	After 36 days 50–60% degraded at pH 3.5, fully hydrolised at pH 7.4 by day 9	Stable for several months at pH 3 or more
Temperature	Unchanged after 1 h at 150°C, pH 3.3–8.0	Temperature-dependent decomposition; in aqueous solution, pH 2.1, hydrolises producing 350 mg cyclohexylamine per kg cyclamate at 30°C, 500 mg kg^{-1} at 44°C, after 40 days	Unstable at high temperatures	Stable to pasteurisation and sterilisation if pH >3 and to baking at temps. >200°C
Storage	Stable in dry form for several years	Stable in tablet form for several years; in aqueous solution hydrolises slowly to sulphuric acid and cyclohexylamine	Stable in dry form; unstable in aqueous solution, 50% degraded after 36 days	Shelf-life of >5 years in solid form; no hydrolysis of sterilised solution stored one month at 40°C
Other		Decomposition accelerated in presence of amino acids and water-sol. vitamins at elevated temps.		
Melt point	229–230°C		246–247°C	Decomposition at 225°C on slow heating
Browning reaction	None	None	None	None
Cariogenic	Anti-cariogenic	Non-cariogenic	Anti-cariogenic	Non-cariogenic
ADI mg kg^{-1} b.w.	2.5 JECFA	Banned US, 1970 11.0 JECFA 1982	40.0 JECFA	9.0 JECFA 15.0 FDA
Cost vs sucrose (equi-sweet)	Lower	Lower	Higher	Same

Stevioside	Thaumatin	NHDC	Sucralose	RTI-001
Natural extract	Natural extract	Natural or synthetic	Derived from sucrose	Synthetic
1905	1972	Late 1950s	1976	1981
White powder (90% pure)		Crystalline powder	White, crystalline powder	
805	21 000		397.64	
>40% in water, insoluble in ethanol	60% in water, good solubility in ethyl and isopropyl alcohols, glycerol, propylene glycol and higher polyols such as sorbitol. Insoluble in ether, acetone, toluene, and triacetin.	Low solubility, 1.2%, in water	28% at 20°C in water, soluble in lower alcohols and other polar solvents	
Stable in range 3–9	Stable in range 1–9 at ambient temps.	Unstable at low pH	Stable in solution at low pH	After 36 days: no change at pH 3.5, 30–40% degraded in water, 70% degraded at pH 7.4
Stable at room temperature, withstands 100°C 1 h, pH 3–9	Stable to heat in range pH 2.7–6.0, optimum pH 2.8–3.5, withstands 100°C at pH <5.5 for several hours	Adequate stability in formulations; buffered solutions pH 2–1 stable 8 h, at 100°C	Stable in solution at high temperatures as sucrose	Thermostable
Stable at room temp. in citric and phosphoric acidified beverages for 3 and 5 months respectively	Indefinite in dry form; several years for chemically preserved solutions at ambient temps.	Occasional yellow discoloration in aqueous solution	Several years in liquids	Twice the shelf-life of aspartame in acidic solutions
Stable in presence of salt	Taste reduced by mono- and divalent salts, increased by trivalent salts; denatured by metaphosphoric and phytic acids at pH 2.9; loss of sweetness with xanthan, CMC, pectin and alginate; incompatible with carrageenans		Resistant to enzymic hydrolysis	
196–198°C	172–174°C	172–174°C		
None			None with proteins, gums, tannins and other carbohydrates	
Non-cariogenic	Non-cariogenic	Non-cariogenic	Non-cariogenic	Low cariogenic potential
—	'Not specified'			
Lower	Higher			

Sources: Walter and Mitchell (1986); Dodson and Pepper (1985); Bakal (1983, 1987); Lindley (1983); Higginbotham (1979, 1983, 1986); Ripper *et al.* (1986); Sunett® Technical Brochure; Andres (1987); Bakal and O'Brien Nabors (1986); Kasperson and Primack (1986); Joint FAO/WHO (1987); Horowitz and Gentili (1986); von Rymon Lipinski (1986).

2.5.3 *Health and safety*

Aspartame is one of the most thoroughly tested food additives. The safety of aspartame's component amino acids, aspartic acid and phenylalanine, and of its metabolite, methanol, has been questioned. However, toxicity is always dose-related and substantial safety margins have been reported with respect to amounts likely to be consumed in the human diet (Ripper *et al.*, 1986). Garriga and Metcalfe (1988, cited by Anon, 1989a) concluded, from an analysis of adverse reactions and clinical data, that aspartame is remarkably safe. However, appropriate warnings on product packaging are necessary to alert sufferers of phenylketonuria, since there is a need to control the amount of phenylalanine in their diets.

2.5.4 *Regulations*

Aspartame achieved FDA approval in 1974 for use as a sweetener, flavour enhancer and as an ingredient in some dry food products. However, objections to the approval led to its suspension pending authentication of the safety studies. In 1981, the FDA reinstated the original approval and, in 1983, granted permission for aspartame's use in carbonated beverages and carbonated beverage syrups. A further amendment extended its use to chewable multivitamin tablets (Ripper *et al.*, 1986). By 1987, four more approved food categories had been added. These were frozen juice drinks, frozen novelties on a stick, tea beverages and breath mints (Andres, 1987).

Aspartame is now a permitted food and beverage additive and/or table-top sweetener in more than 50 countries (Ripper *et al.*, 1986).

2.5.5 *Applications*

The availability of aspartame has contributed greatly to the upsurge in low-calorie products in the market place. Its good taste, as well as its make-up from food-associated amino acids, have promoted its acceptability. Its popularity has been in spite of the high cost of aspartame, relative to other sweeteners and sucrose. However, the price can be expected to be reduced after Searle's US patent expires in 1992, because of the entry of competing manufacturers into the market place. One poised to do so is a Japanese–Dutch firm called Toyo-DSM Aspartame VOF (Anon, 1986b).

Aspartame blends well with other food flavours, but interacts with them differently than does sucrose, and so should not be used as a simple substitution for sucrose in formulations (Mazur and Ripper, 1979). It also has flavour-enhancing properties particularly with citrus fruit drinks.

The unstable character of aspartame has placed limitations upon its applications. However, these have been overcome or accommodated to

some extent. For instance, although conditions of pH, temperature and moisture cause loss of aspartame due to decomposition, together with reduced sweetness, it has been shown that overall acceptability of certain carbonated, soft drinks is not affected pro rata, but remains high over a wide range of concentrations (Ripper *et al.*, 1986). Also, processing of foods containing aspartame at high temperatures is now possible with HTST (high temperature/short time) technology. Dairy products can be pasteurised by this method, and applications in the bakery industry are no longer impossible (Andres, 1987).

2.6 Acesulfame-K

2.6.1 *General*

Acesulfame-K is a potassium salt derived from acetoacetic acid, with a chemical formula of $C_4H_4NO_4KS$ and a molar mass of 201.2 (Sunett® Technical Brochure). This sweet-tasting compound was discovered by accident by the employees of Hoechst AG in 1967, and is currently marketed by Hoechst under the trade name of Sunett®.

2.6.2 *Mixtures*

Mixtures of sweeteners may be advantageous for improving the taste profile, or for economic reasons where there is synergism. Although acesulfame-K can be used alone in foodstuffs, there are practical benefits of combining it with bulk sweeteners in some applications. Combinations of acesulfame-K with sorbitol in a ratio of 1:150–200, with sucrose in a ratio of 1:100–150, with isomalt in a ratio of 1:250–300, and with maltitol in a ratio of 1:150 provide mixtures with a 1:1 ratio on a sweetness basis that appear to give the best taste profiles (von Rymon Lipinski, 1985). Acesulfame-K is said to round up the weak sweetness of sorbitol, and provide a more fully developed taste (von Rymon Lipinski, 1982).

Acesulfame-K produces a pronounced synergistic effect of sweetness intensity of up to 30% or more in combination with cyclamate and with aspartame, but a barely noticeable effect with saccharin (Table 2.3). The most favourable sensory properties were observed using combinations having inverse ratios of the components' sweetness intensities, e.g. 1:1 by weight for acesulfame-K and aspartame, and 1:5 by weight for acesulfame-K and sodium cyclamate (von Rymon Lipinski, 1986). Acesulfame-K is also synergistic with the nutritive sweeteners sorbitol, isomalt and fructose (Sunett® Technical Brochure) (Table 2.3).

There may also be a cost advantage in combining acesulfame-K with

Table 2.3 Sensory properties of intense sweeteners

	Sweetness intensity	Sweetness quality	Synergistic with:
Sucrose	1	Clean sweetness; no after-taste	Saccharin, aspartame, cyclamates, stevioside
Sodium saccharin	200–700	Sweet; bitter, metallic after-taste	Cyclamates, aspartame, sucrose, isomalt, stevioside, NHDC
Sodium cyclamate	30–140	'Chemical' sweet; no after-taste	Saccharin, sucrose, aspartame, acesulfame-K
Aspartame	160–200	Clean sweetness; sweet after-taste	Saccharin, cyclamates, sucrose, glucose, acesulfame-K, isomalt, stevioside
Acesulfame-K	200	Sweet; slight bitter after-taste	Aspartame, cyclamate
Stevioside	300	Slow onset; lingering, liquorice, bitter after-taste	Sucrose, glucose, fructose, aspartame, glycyrrhizin
Thaumatin	1500–2500	Slow onset; lingering, liquorice after-taste	Saccharin, acesulfame-K, stevioside
NHDC	1500–2000	Delayed onset, cooling, menthol-like taste	Most sweeteners
Sucralose	400–800	Sweet taste close to sucrose, very slight delay and lingering of sweetness	
RTI-001	58	Sucrose-like taste, no after-taste	

Sources: von Rymon Lipinski (1986, 1987); Seltzman *et al.* (1985); Anon (1988); Gelardi (1987); Bakal (1983, 1987); Lindley (1983); Ripper *et al.* (1986); Sunett® Technical Brochure; Higginbotham (1983, 1986); Anon (1987b); Crosby and Wingard (1981).

thaumatin, since this mixture reputedly provides an equivalent taste in some products to that of aspartame, a more costly sweetener (Anon, 1987b).

2.6.3 *Health and safety*

No adverse reactions in the body to the consumption of acesulfame-K have been found despite extensive safety studies. The Joint FAO/WHO Expert Committee on Food Additives (JECFA) allocated an ADI of 0–9 mg kg^{-1} of body weight in 1983, having found that acesulfame-K was neither mutagenic nor carcinogenic, and with no other toxicological problems. It is not metabolised in the body, is excreted rapidly and completely, and thus has

no calorific value and is suitable for diabetics. It is also considered to be non-cariogenic, since the acute oral toxicity of acesulfame-K use is extremely low (von Rymon Lipinski, 1986).

2.6.4 *Regulations*

Acesulfame-K was first cleared by the Food Additives and Contaminants Committee (FACC) for use in the UK, with effect from 1983. It has been accepted for food use by WHO/FAO and by the Scientific Committee for Foods of the EEC with an ADI of 0–9 mg kg^{-1} of body weight. More recently, the FDA granted an ADI of up to 15 mg kg^{-1} of body weight. This rate of addition to foods and beverages should be sufficient to safely replace all of the sugar consumed in the diet for most people. In addition to the UK and US, acesulfame-K has been approved in many other countries, including Germany, Russia, Australia, South Africa, Cyprus, Belgium, Denmark and Egypt. Its approval has also been granted for use in toothpaste by Bulgaria and the USSR, although no official approval is required by many countries for its use in oral-hygiene products because of its demonstrated safety (von Rymon Lipinski, 1986).

2.6.5 *Applications*

Because of its good solubility and stability in aqueous media, acesulfame-K is particularly suitable for sweetening soft drinks. At a given concentration, acesulfame-K imparts a slightly higher sweetness in acid foods and beverages than in neutral ones (Luck, 1981). Sweetness intensity is not reduced in hot drinks, relative to those at room temperature, to the same extent as occurs with other sweeteners (Sunett® Technical Brochure). It can be added to liquid concentrates, and there is no hydrolytic decomposition of stock solutions at the usual pH range of drinks, i.e. at pH 3 and above, over a period of months. Also, because of its heat stability, aceslfame-K can be processed in spray towers or for production of instant beverage powders. As a single sweetener, 400–700 mg l^{-1} produces a medium sweetness in drinks. Blending with another sweetener in soft drinks should be arranged so that each contributes 50% of the sweetness to obtain the best taste profile. Acesulfame-K is compatible with all sugars, both chemically and sensorily, and a particularly pleasant taste is achieved upon mixing with other high-intensity sweeteners, especially aspartame and cyclamate (Sunett® Technical Brochure).

Acesulfame-K can readily be used in the production of table-top formulations, as solutions or spray-dried granular or powder preparations, because of its solubility in water and heat stability. Solutions should be adjusted to a pH range of 5.5–6.0 with appropriate buffer systems. Compression into

tablets, however, requires the addition of a disintegrant such as low-viscosity carboxymethyl cellulose or polyvinyl pyrrolidone. Effervescent tablets can be produced with the addition of sodium hydrogen carbonate as the carbon dioxide donor and tartaric acid as the acid medium, and benefit from the addition of small amounts of cold-water-soluble gelatin. Effervescent tablets have a good shelf-life stored in a dry place. Acesulfame-K can also be mixed with inert substances, or with citrates, tartrates, lactose and/or sugar alcohols to produce tablet-top powders. Mixing with pure cellulose provides calorie-free dustings that are visually attractive on some products.

Acesulfame-K can be combined with pectins and other gelling agents providing bulk in the production of low-calorie preserves, or with sorbitol in sugar-free jams and marmalades. However, such products are more susceptible to spoilage by microorganisms than sugar-containing preserves, and should either be pasteurised or include 0.05–0.1% potassium sorbate as a preservative where permitted. Acesulfame-K is best added as an aqueous solution, thus aiding even dispersion, in the range of 500–2500 mg kg^{-1} of final product.

Because of its good heat stability, acesulfame-K can be used to replace sugar in confectionery (1000–3000 mg kg^{-1}) and in bakery products (500–2000 mg kg^{-1}) together with polydextrose, disaccharide alcohols, sorbitol or isomalt to provide bulk. Concentrations of 500–600 mg kg^{-1} are recommended in desserts, and 500–3000 mg kg^{-1} in sugar-free chewing gum. In the production of sugar-free ice cream, about 500 mg kg^{-1} may be added to supplement sugar alcohols and to achieve a well-balanced taste. Acesulfame-K does not affect the melting and whipping properties of the ice-cream mix.

Acesulfame-K has applications in other products, too. It can be used to sweeten fruit products, fruit yoghurt, sandwich spreads and pickles. It is also suitable for sweetening pharmaceuticals and oral hygiene products, such as toothpaste and mouthwashes, since it masks the bitter or other unpleasant taste characteristics of other product components (Sunett® Technical Brochure).

2.7 Stevioside

2.7.1 *General*

Stevioside, sucrose and thaumatin are the only sweeteners extracted and refined from plants without chemical or enzymic modification (Phillips, 1978). Stevioside is a sweet glycoside extracted from the leaves of the plant *Stevia rebaudiana* Bertoni, a variety of chrysanthemum found wild in areas of Paraguay and Brazil. The plant has been successfully cultivated in other countries including Japan, Korea, Taiwan and China.

Although other grades of purity exist, stevioside is commercially available

in Japan in three basic forms: crude extract, 50% pure, and 90% pure or higher. The taste profile improves with increasing purity. However, a compound that has even better organoleptic properties, i.e. less after-taste, than 90% stevioside is Rebaudioside A. Rebaudioside A is a constituent of stevioside, that has been isolated and the subject of US and Japanese patent applications (Bakal and O'Brien Nabors, 1986).

2.7.2 *Mixtures*

As a single sweetener, stevioside produces an unacceptable liquorice-like taste in cola beverages. Its combination with fructose, though, has been successfully used in Japan to produce calorie-reduced (50%) soft drinks (Bakal, 1987). Stevioside is combined with sugar alcohols in sugarless chewing gums, and with sucrose in calorie-reduced sugar cubes. The mixture of stevioside with glycyrrhizin is synergistic and is available commercially from Japanese manufacturers. Synergism has also been found (Table 2.3) with aspartame, cyclamate and acesulfame-K, but not with saccharin (Bakal and O'Brien Nabors, 1986).

2.7.3 *Health and safety*

The results of standard short-term tests, with rats and silkworms from several laboratories, indicate no significant mutagenic or genotoxic activity for stevioside. Human experience of long and extensive use, particularly in Japan, suggests the safety and lack of toxicity of stevioside (Bakal and O'Brien Nabors, 1986). However, it remains uncertain as to whether stevioside and rebaudioside are degraded in the human bowel to steviol, with associated biological risks.

2.7.4 *Regulations*

Clearance is not needed in Japan for natural products, and stevioside is a permitted additive there as well as in Brazil and Paraguay. Safety evaluations have not yet been completed in Western countries, however.

2.7.5 *Applications*

Stevioside is currently used in Japan in sugarless chewing gums, soft drinks, table-top sweeteners, juices and other products. Gums sweetened with stevioside enjoy high consumer acceptance, despite the differences between these products and saccharin and aspartame-sweetened products (Bakal, 1987). Stevioside is also added, in Japan, to products such as pickles, dried

seafoods, fish, meat and bean pastes and soy sauce as a flavour modifier and to suppress pungent flavours (Bakal and O'Brien Nabors, 1986).

2.8 Thaumatin

2.8.1 *General*

Thaumatin is a mixture of intensely sweet-tasting proteins extracted from the fruit of a West African plant, *Thaumatococcus daniellii.* The two major sweet-tasting proteins, thaumatin I and II (TI and TII), were isolated by Van der Wel and his group at Unilever in 1972. Thaumatin is marketed in the UK by Tate & Lyle plc as Talin, although the fruit of the plant has been used for centuries by the West Africans as a source of sweetness. It is also sold in Japan. Because of problems with stability, taste profile and compatibility, thaumatin is used primarily as a flavour enhancer, at levels below the sweet-taste threshold.

2.8.2 *Mixtures*

Thaumatin is synergistic with saccharin, and masks saccharin after-taste when used at low levels. Synergism is also found with acesulfame-K and with stevioside (Table 2.3), but not with cyclamate or aspartame (Higginbotham, 1986). A combination of thaumatin and acesulfame-K is said to provide a less costly alternative to aspartame with equivalent taste in some products (Anon, 1987b).

2.8.3 *Health and safety*

Thaumatin is the only natural high-intensity sweetener, and products containing it do not require to be labelled 'artificially sweetened'. It has a low calorific value and is non-cariogenic (Higginbotham, 1986). The report of the Joint FAO/WHO Expert Committee (1987) recorded no mutagenic, teratogenic or allergenic effects of thaumatin, and concluded that the lack of toxicity, together with its ready digestion to normal food components, indicated that its only dietary effect was to make an insignificant contribution to the normal protein intake.

2.8.4 *Regulations*

Thaumatin has been permitted as a natural food in Japan since June 1979. It was awarded GRAS status for use in chewing gum in the USA in October

1984 and, in the UK, was permitted for use in foods, drinks and dietary products, excluding baby foods, by the Sweeteners in Foods Regulations in 1983. The Joint FAO/WHO Expert Committee declared an ADI 'not specified' for thaumatin in 1985 (Joint FAO/WHO, 1987). Approval has also been gained in many countries world wide for use of thaumatin as a sweetener and flavour enhancer, particularly in chewing gum. These include Australia, Belgium, Spain, Switzerland, Mexico and Denmark (Higginbotham, 1986).

2.8.5 *Applications*

As a sweetener, thaumatin is used in beverages and desserts, but its applications are limited because of its liquorice taste and delayed sweetness (Gelardi, 1987). In practice, therefore, thaumatin is more commonly used as a partial sweetener, mixed with other more rapidly tasting sweeteners (Higginbotham, 1986).

Despite its limitations as a sweetener, thaumatin is a powerful flavour enhancer, and magnifies spearmint, cinnamon, wintergreen and peppermint by up to ten times. This flavour potentiating characteristic, together with the lingering sweet taste, can be beneficially used for products such as toothpaste, mouthwash and chewing gum, and for enhancing the masking flavours in medicines. Thaumatin also boosts the low sweetness of bulk sweeteners added to sugarless gums, without adding calories or cariogenicity (Higginbotham, 1983, 1986).

Thaumatin has been used in Japan since 1979 in a variety of products, where it has been shown to enhance and improve the flavour of coffee and of milk products. It is thus used in coffee-flavoured products, ice-cream, iced milk drinks-on-sticks, and spray-dried milk powders. It also enhances savoury flavours (Higginbotham *et al.*, 1981; Higginbotham, 1986), and combinations of thaumatin with nucleotides, spices and/or other flavours may be used to replace monosodium glutamate, an ingredient of current concern with regard to safety (Anon, 1987b).

2.9 Neohesperidin dihydrochalcone

2.9.1 *General*

In the late 1950s Horowitz and Gentili discovered that a bitter flavanone, hesperetin, found in the peel of the Seville orange, could be chemically converted by alkaline hydrogenation to a sweet compound, neohesperidin dihydrochalcone (NHDC). A straightforward synthetic route has now been developed as an alternative method of its production. Time-intensity studies

show that the taste profile of NHDC is unlike that of sucrose, with a delayed onset of menthol-like sweetness and a lingering after-taste (Crosby and Wingard, 1981).

2.9.2 *Mixtures*

The mixture of NHDC with saccharin produces synergistic sweetness (Table 2.3) and an improved taste profile in soft drinks (Bakal, 1987). Mixing NHDC with other ingredients, such as cream of tartar, a carbohydrate bulking agent and vanilla flavour reputedly eliminates delayed onset and after-taste, while the addition of gluconates, amino acids or nucleotides improves the sweetness (Higginbotham, 1983).

2.9.3 *Health and safety*

Safety studies have been conducted with laboratory animals mainly in the US over the past fifteen years. The results have suggested that NHDC is neither toxic, mutagenic, carcinogenic, teratogenic nor cariogenic (Horowitz and Gentili, 1986). These results are possibly unsurprising since flavenoids are common constituents of the diet, and only minute quantities of NHDC would normally be consumed.

2.9.4 *Regulations*

NHDC is currently permitted as a sweetener in several countries, including Belgium, where it may be added to chewing gum and some beverages (Horowitz and Gentili, 1986). Regulatory clearance has been sought in Israel, America and Spain to develop and manufacture NHDC, since these countries have large resources of citrus materials. However, toxicological data presented to the FDA did not conform to the required guidelines, and GRAS status was not awarded.

2.9.5 *Applications*

NHDC is incompatible with other flavour components in most food applications, including tea and coffee, and is a poor substitute for sucrose because of the delayed onset of sweetness and the menthol-like taste (Crosby and Wingard, 1981). Up to 25% of the sweetness in soft drinks can be contributed by NHDC before the taste becomes unacceptable. However, it provides an acceptable sweetness profile and flavour-enhancing properties in chewing gum, candies, toothpastes and mouthwashes, since these are products that benefit from long-lasting sweetness. NHDC is said to preserve

the flavour and aroma of chewing gum at low levels (Higginbotham, 1983). NHDC may be combined with bulking agents such as sugar alcohols in some applications, particularly in view of its high potency.

Although the sensory properties of NHDC-sweetened products and those of products sweetened with saccharin or aspartame are different, consumer acceptance is high in Japan (Bakal, 1987). Applications of NHDC include sweetening cultured milk products, suppressing salt taste in highly brined traditional Japanese foods, and as a tobacco flavourant (Higginbotham, 1983).

NHDC has the propensity for reducing bitterness, as well as providing sweetness, and is thus suitable for inclusion in bitter-tasting drugs and in grapefruit juice (Horowitz and Gentili, 1986).

2.10 Sucralose

2.10.1 *General*

Sucralose is a non-caloric, high-intensity sweetener currently under development. It is derived by the selective chlorination of sucrose at the molecular 4, 1′, and 6′ positions by a patented process developed by Tate & Lyle, London. The sweetener is being jointly developed by Tate and Lyle Speciality Sweeteners in the UK and McNeil Speciality Products Company, a subsidiary of Johnson and Johnson, in the US (Anon, 1988).

2.10.2 *Health and safety*

A comprehensive range of safety evaluation studies has shown that sucralose is not toxic, carcinogenic, teratogenic or mutagenic (Daniel and Das, 1980; Anon, 1988). It is also non-caloric and is not conducive to the formation of dental caries (Higginbotham, 1983).

2.10.3 *Regulations*

Approval of sucralose as a food additive is being sought in a number of countries including the UK, Canada and the US.

2.10.4 *Applications*

Successful applications of sucralose in a wide range of products was reported by Miller, of McNeil Speciality Products Company (Anon, 1988). These include still and carbonated beverages, dry milk products, frozen foods, chewing gum, baked products, fruit spreads and syrups.

2.11 RTI-001

2.11.1 *General*

A new peptide sweetener has been developed at the Research Triangle Institute (RTI), in the US, that is 58 times sweeter than sucrose, has a pleasant sucrose-like taste, and is more stable in aqueous media than aspartame (Seltzman *et al.*, 1985). A US patent (Patent no. 4,714,619) was applied for by Seltzman *et al.*, of the RTI, in December 1987. The authors recommend that, on account of its taste, stability and non-toxicity, this sweet compound should have further consideration as a sucrose substitute. Seltzman further predicts its availability in 5–10 years (Anon, 1986).

2.11.2 *Health and safety*

The compound RTI-001 was tested at the Research Triangle Institute by means of the Ames assay and mouse toxicity studies, and was shown to be non-mutagenic and non-toxic (Seltzman *et al.*, 1985).

2.11.3 *Applications*

The stability of RTI-001 in aqueous and acid media (Seltzman *et al.*, 1985), with twice the shelf-life of aspartame (Anon, 1986), demonstrates its potential for use in soft drinks.

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