4 Carbohydrate and intense sweeteners
K. O’Donnell

4.1 Overview

The profile of bulk and intense sweetener use in soft drinks has changed significantly over the last 10–15 years. Several reasons have caused this change in formulations:

(1) technical improvements in the manufacture of bulk sweeteners with different carbohydrate profiles that deliver equivalent sweetness and mouthfeel properties to sugar at lower cost;
(2) deregulation of some soft drinks markets, allowing combinations of bulk and intense sweeteners to be used in non-diet products;
(3) sweetener development – improvement of taste quality and number of intense sweeteners available for soft drinks formulations;
(4) increasing consumer awareness of healthy eating and concern about the growing incidence of obesity and Type 2 diabetes in the Western world, leading to an increased number of low- and reduced-sugar formulations.

The use of carbohydrate sweeteners in juices and drinks has increased ever since the times of Captain Cook, when sugar was used to preserve juices. Sugar (sucrose) is still regarded as the ‘gold’ standard for taste delivery and mouthfeel. Carbohydrate-based sweeteners still represent the largest share of the global sweetener market and currently account for 81% of sweetener usage (Cosgrove, 2003). Figures 4.1 and 4.2 show the current split globally and in the United States of various sweeteners.

High-fructose corn syrups dominate the carbohydrate-sweetened soft drinks sector in some markets – notably in the United States. However, in other markets, for example, Europe, the use of high-fructose glucose syrups (HFGS) is restricted by production quotas, and a variety of carbohydrate products including sucrose, glucose syrups, fructose and fructose syrups are used.

4.2 Carbohydrate sweeteners

A number of carbohydrate sweeteners are used in soft drinks and they provide different attributes, including sweetness, mouthfeel, stability and, in some cases, colour. Table 4.1 summarises the properties of some carbohydrate sweeteners that are, or could be, used in soft drinks.
4.2.1 Sucrose

Sucrose is regarded as the ‘gold’ standard for a sweet taste. It is manufactured from cane or beet and available in crystalline or liquid form. Sucrose is a disaccharide with a molecular weight of 342.31. It is available in a very pure state and in a variety of physical forms.

4.2.1.1 Manufacture

Juice extracted from cane or beet undergoes further purification steps, including precipitation, absorption, crystallisation and evaporation, which remove non-sugars and progressively concentrate the sucrose solution. The final step is crystallisation of sucrose from the syrup. This mixture of sucrose and liquor, known as the ‘massecuite’, is then centrifuged, and the crystals are washed and dried to a moisture content of 0.02% w/w and stored (Beesley, 1990).

Figure 4.1  Estimated sweetener market (equivalent sweetness basis): (a) global (b) United States. Source: Ajinomoto.
Table 4.1 Properties of bulk sweeteners

<table>
<thead>
<tr>
<th>Sweetener/carbohydrate</th>
<th>Relative sweetness (Sucrose = 1)</th>
<th>Solubility (g/100 g water at 20°C)</th>
<th>Insulin-dependent metabolism</th>
<th>Caloric value (kcal/g)</th>
<th>Approval for use in soft drinks</th>
<th>Dietary fibre approval</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>EU</td>
<td>USA</td>
</tr>
<tr>
<td>Sucrose</td>
<td>1</td>
<td>200</td>
<td>Yes</td>
<td>4</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Glucose syrup</td>
<td>0.6</td>
<td>High a</td>
<td>Yes</td>
<td>4</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>HFGS</td>
<td>0.9–1.0</td>
<td>High b</td>
<td>Yes</td>
<td>4</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Fructose</td>
<td>1.2–1.8</td>
<td>374.83</td>
<td>No</td>
<td>4</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>FOS</td>
<td>0.3–0.6</td>
<td>75</td>
<td>No</td>
<td>2</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Inulin</td>
<td>0</td>
<td>10</td>
<td>No</td>
<td>1</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Polydextrose</td>
<td>0</td>
<td>80</td>
<td>No</td>
<td>1</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Trehalose</td>
<td>0.45</td>
<td>40.8</td>
<td>Yes c</td>
<td>4</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Tagatose</td>
<td>0.92</td>
<td>62.0</td>
<td>No</td>
<td>1.5</td>
<td>No</td>
<td>Yes</td>
</tr>
</tbody>
</table>

a Solubility good, but varies with products of different specifications.
b Approved as dietary fibre in Belgium and Finland.
c Glucose and insulin responses lower than glucose.

Liquid sugar is readily available as an aqueous solution, usually at 67% w/w (67°Brix) at 20°C. It is manufactured by dissolving granulated sugar in water at an elevated temperature. The product may then be further refined by carbon filtration and de-ionisation. It may then be further treated using ultraviolet (UV) light to reduce microbial contamination.
4.2.2 Glucose syrups/high-fructose glucose syrups

Glucose syrups, also known as corn syrups in the United States, are defined by the European Commission (EC) as ‘a refined, concentrated aqueous solution of \( \text{D}(+)-\text{glucose} \), maltose and other polymers of \( \text{D}-\text{glucose} \) obtained by the controlled partial hydrolysis of starch’ (Howling, 1984). Glucose syrups were first manufactured industrially in the nineteenth century by acid hydrolysis of starch. Hydrochloric acid was normally used, because sulphuric acid caused haze in syrups due to insoluble sulphates. The source of starch can vary; in the United States corn is widely used, whereas in other parts of the world wheat, potato and cassava starch are also employed. Acid hydrolysis of starch is still used today. The method is non-specific, but if conditions are tightly controlled, it is possible to make products with a reasonably consistent carbohydrate profile.

The degree of hydrolysis is defined by the ‘DE’ value or ‘dextrose equivalent’. Starch (with no hydrolysis) has a DE of 0. Glucose or dextrose, which is starch that has been totally hydrolysed, has a DE of 100. The DE value is the total reducing sugar content of the syrup, compared to \( \text{D}(+)-\text{glucose} \) on a dry matter basis. As the DE increases, the viscosity of glucose syrups decreases, due to the proportion of shorter chain molecules increasing relative to the longer polysaccharide chains. In the soft drinks industry glucose syrups with DE values in the range 42–63 are commonly used.

Enzymes are also used to hydrolyse starch to glucose syrups, and these give a greater degree of control over the sugar profile of the resulting syrup. The availability of commercial isomerase enzymes in the 1970s, which are capable of converting glucose to fructose, allowed significant development of the production of high-fructose corn syrups with fructose levels of 42% and a sweetness level equivalent to sucrose. Use of separation technology allowed further refinement of these products to give 55% fructose syrups. These types of syrups are used extensively in the soft drinks industry, particularly in the United States. It is now possible to tailor-make syrups with a given carbohydrate profile to optimise the combination of specific properties of the different carbohydrate fractions.

In soft drinks, glucose syrups are used to provide sweetness and mouthfeel to products and occasionally specific physiological properties in sports and energy drinks. Glucose syrups are significantly less sweet than corresponding sucrose solutions (glucose has a relative sweetness of 0.6), unless they have a high fructose content.

4.2.3 Fructose (levulose)

Fructose can also be used as a sugar substitute in crystalline or syrup form. It is present naturally in many fruits and in honey, but commercially it is manufactured using sucrose as a starting material. Sucrose is first hydrolysed to
Fructose is unique among known sugars in being sweeter than sucrose. In solution, fructose can exist as four or five isomers, and the relative sweetness of a solution is dependent upon the equilibrium between the sweeter pyranose isomers and the less sweet furanose isomers, which is in turn dependent on such conditions as pH and temperature. In cold conditions the pyranose form predominates and, therefore, fructose solutions are sweeter (Danisco Sweeteners, 2003). Fructose has a clean, sweet taste; it is also synergistic with many bulk and intense sweeteners and is often used at low levels to improve the taste profile of some intense sweeteners. It is very soluble and also relatively hygroscopic, compared with sucrose (Danisco Sweeteners, 2003).

Fructose has some interesting physiological properties. It is a monosaccharide sugar with an energy content of 4 kcals/g (17 kJ/g) but due to its increased sweetness can be used at lower levels than sucrose. Fructose is slowly absorbed and metabolised by the body, independent of insulin production, and does not cause rapid rises in blood glucose after ingestion. It is, therefore, suitable for diabetics and also for use in drinks intended to act as a slower, more sustained energy source. Owing to its limited effect on blood glucose, it is a low glycaemic index sweetener (compared with glucose). This is an area of increased nutritional interest and may be a stimulus to the greater use of fructose in drinks. Fructose has also been shown to have an increased satiety effect, compared with other sweeteners (Spitzer and Rodin, 1987). Mineral absorption (iron and calcium) has also been shown to be positively affected by the incorporation of fructose into the diet (Holbrook et al., 1989).

Chemically, fructose is very active and it readily takes part in maillard reactions, which may cause browning in some products. It is available in crystalline anhydrous form and also in high-concentration syrups.

4.3 Overview – intense sweeteners

The use of intense sweeteners in soft drinks has increased dramatically over the period 1985–2004. Saccharin was the first high-intensity sweetener to be marketed and its usage increased during the First World War as a result of sugar scarcity. Cyclamate entered the UK market during the 1960s, but was controversially banned in many countries as it was thought to be a potential carcinogen.

The 1970 cyclamate ban ended the use of saccharin/cyclamate blends in many soft drinks markets. The effect of this was that the low-calorie soft drinks market remained small and static owing to the poor taste quality of products available. The introduction in 1982–83 of aspartame in particular, and acesulfame K to a lesser extent, into the global soft drinks market dramatically improved the
taste quality of sugar-free soft drinks formulations. There followed a period of rapid growth in the low-calorie sector. The use of intense sweeteners in soft drinks was given a further boost in the UK market when, in 1995, the requirement for a minimum carbohydrate level of 4.5°Brix in non-low-calorie products was removed. Products were reformulated to incorporate blends of intense sweeteners and low levels of carbohydrate sweeteners (around 0.5–3.0°Brix) to deliver cost savings without compromising taste quality. Over time, and as the use of intense sweeteners expanded, optimisation of the sweetener blends continued to deliver excellent tasting products. Currently, in the UK market, 50% of all beverages contain intense sweeteners, even though the diet market is only 25% of the total (Cosgrove, 2003). In the United Kingdom, Diet Coke now outsells regular Coke (The Grocer, 2003).

Harmonisation of the EU Sweetener Regulations in 1994 (94/35/EC; as amended in 1996 – 96/83/EC) saw approvals for aspartame and acesulfame K extend across the European Union and for the reintroduction of cyclamate into the UK market. In 2002, sucralose was approved for use in the United Kingdom – its first introduction into a European market. In 2004, sucralose approval was extended across the EU.

Formulators in most markets now have a wide range of sweeteners available to use either alone or in combination. As Figures 4.1 and 4.2 show, the main intense sweeteners in use in soft drinks today are acesulfame K, aspartame, saccharin and cyclamate. Currently of less importance commercially (either because they are new to the market or because they have not found significant use in soft drinks), but still approved for use in soft drinks in some markets, are thaumatin, neohesperidin dihydrochalcones, alitame, stevioside, sucralose and neotame.

4.3.1 Sweetener approval

The main intense sweeteners currently permitted for use in the major markets of Europe and the United States are not natural and have had to go through a food additive approval procedure. Within the European Union, approval is controlled by the EU Commission, with the aim of achieving harmonisation across member states. The current system allows for temporary national approval (and this was the mechanism by which sucralose was approved in the United Kingdom). This in turn allows the other EU countries time to review the data and either approve or reject each product within a specified period. Within the European Union, approved sweeteners are assigned an ‘E’ number and can also be assigned a maximum use level within a specific application (e.g. soft drinks). The maximum use levels for sweeteners in soft drinks in the European Union are given in Table 4.2.

When assigning maximum use levels, the regulators take into account a sweetener’s likely intake across different population groups and its ‘acceptable
daily intake’ (ADI). This ADI of sweeteners (and other food additives) is the estimated amount of the product expressed as milligrams per kilogram of body weight that can be consumed every day throughout a lifetime without any harmful effects. ADI levels are set by the Joint FAO/WHO Expert Committee on Food Additives (JECFA) after reviewing the toxicology data generated by feeding trials. Generally, the ADI is set at one-hundredth of the intake level that shows no harmful effects. The ADI levels for the intense sweeteners are given in Table 4.2.

In the United States, the Food and Drug Administration (FDA) assesses the safety and suitability of potential new sweeteners, giving GRAS (generally recognised as safe) status to products that are viewed as being safe and suitable for food use. In addition, the FDA can give ‘good manufacturing practice’ (GMP) status, which means that there are no upper limits for use of these ingredients.

### 4.3.2 Labelling

In the United Kingdom, intense sweeteners can be described on ingredient listings as ‘Sweetener (name)’ (e.g. ‘Sweetener aspartame’) or ‘sweetener E-number’

<table>
<thead>
<tr>
<th>Sweetener</th>
<th>EU Solubility (g/l)</th>
<th>Caloric value (kcal/g)</th>
<th>Nutritive value (%)</th>
<th>ADI (mg/kg bw)</th>
<th>Approval in EU</th>
<th>Approval in USA</th>
<th>Max. use level (ppm)</th>
<th>Relative sweetness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acesulfame K</td>
<td>950</td>
<td>270</td>
<td>0</td>
<td>9</td>
<td>Yes</td>
<td>Yes GMP</td>
<td>350</td>
<td>200</td>
</tr>
<tr>
<td>Aspartame</td>
<td>951</td>
<td>10</td>
<td>4</td>
<td>40</td>
<td>Yes</td>
<td>Yes GMP</td>
<td>600</td>
<td>200</td>
</tr>
<tr>
<td>Cyclamate</td>
<td>952</td>
<td>200</td>
<td>0</td>
<td>7</td>
<td>Yes</td>
<td>No</td>
<td>250</td>
<td>35</td>
</tr>
<tr>
<td>Saccharin (sodium salt)</td>
<td>954</td>
<td>3,700</td>
<td>0</td>
<td>2.5</td>
<td>Yes</td>
<td>Yes GMP</td>
<td>80</td>
<td>400</td>
</tr>
<tr>
<td>Stevioside</td>
<td>Not approved</td>
<td>1.2</td>
<td>0</td>
<td>N/A</td>
<td>No</td>
<td>No</td>
<td>N/A</td>
<td>70–300</td>
</tr>
<tr>
<td>Sucralose</td>
<td>955</td>
<td>280</td>
<td>0</td>
<td>15</td>
<td>In UK</td>
<td>Yes GMP</td>
<td>300</td>
<td>450</td>
</tr>
<tr>
<td>Alitame</td>
<td>N/A</td>
<td>131</td>
<td>1.4</td>
<td>0.1</td>
<td>No</td>
<td>No</td>
<td>N/A</td>
<td>2000</td>
</tr>
<tr>
<td>Neotame</td>
<td>N/A</td>
<td>12.6</td>
<td>0</td>
<td>Not assigned</td>
<td>No</td>
<td>Yes GMP</td>
<td>N/A</td>
<td>8000</td>
</tr>
<tr>
<td>NeoDHC</td>
<td>959</td>
<td>0.5</td>
<td>0</td>
<td>5</td>
<td>Yes</td>
<td>No</td>
<td>30</td>
<td>300–600</td>
</tr>
<tr>
<td>Salt of aspartame–acesulfame</td>
<td>951,950</td>
<td>23</td>
<td>2.56</td>
<td>––c</td>
<td>In UK and NL</td>
<td>––d</td>
<td>––e</td>
<td>350</td>
</tr>
</tbody>
</table>

---

<table>
<thead>
<tr>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>a In soft drinks in the European Union.</td>
</tr>
<tr>
<td>b 5% equivalent; sucrose = 1.</td>
</tr>
<tr>
<td>c ADI covered by ADI for constituent parts (i.e. aspartame and acesulfame).</td>
</tr>
<tr>
<td>d Not required as aspartame and acesulfame are approved.</td>
</tr>
<tr>
<td>e Maximum level should not exceed maximum levels for constituent parts.</td>
</tr>
</tbody>
</table>

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Table 4.2 Physiochemical and regulatory properties of intense sweeteners

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CHEMISTRY AND TECHNOLOGY OF SOFT DRINKS AND FRUIT JUICES

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(e.g. ‘Sweetener E951’). The label should make it clear to the consumer that the product contains sweetener and have ‘with sweetener’ close to the sales denomination. Blends of intense sweetener and sugar should have ‘with sugar and sweeteners’ close to the sales denomination. Products containing aspartame should have the additional notice ‘contains a source of phenylalanine’ (EU Food Labelling Regulations, 1996).

4.3.3 Main intense sweeteners in use in soft drinks

Physiochemical and regulatory properties of some intense sweeteners are given in Table 4.2.

4.3.3.1 Acesulfame K

Acesulfame K is the generic name for the potassium salt of 6-methyl-1,2,3-oxathiazine-4(3H)-one-2,2,dioxide. Manufacture is by chemical derivation from acetoacetic acid. It is a white, non-hygroscopic crystalline product. Its solubility in water is good. The relative sweetness of acesulfame K varies from 100 to 200, depending on concentration and application (V on Rymon Lipinsky, 1985).

This ingredient has a fast-onset sweet taste with a marked bitter aftertaste that is more noticeable at high concentrations. Combinations of acesulfame K and aspartame are synergistic with respect to sweetness intensity and sweetness quality when compared with acesulfame K alone. Synergy has also been reported with cyclamate, glucose, fructose, sucrose and sucralose (Nutrinova, 2003; V on Rymon Lipinsky & Huddard, 1983). Negative synergy (i.e. suppression) occurs with acesulfame K/saccharin combinations.

The stability of acesulfame K is very good under most food processing and storage conditions. In general, it does not appear to be reactive with other soft drink ingredients. However, the inclusion of potassium ions through the addition of acesulfame K should be taken into account when selecting clouding agents (Von Rymon Lipinsky, I.C. personal communication 1988).

The maximum use level in soft drinks within the European Union is 350 mg/l and, therefore, it must be combined with other sweeteners to reach a sweetness level of 10°Brix equivalent. Acesulfame K is excreted unchanged from the body, primarily in the urine. It is non-cariogenic and has an ADI of 9 mg/kg bw (Renwick, 1983).

4.3.3.1.1 Analysis. HPLC is the preferred method for analysis of acesulfame K with detection in the UV range (Von Rymon Lipinsky, 1985).

4.3.3.1.2 Use in soft drinks. Use of acesulfame K in soft drinks is largely in combination with one or more other intense sweeteners, in particular aspartame.
There is no commonly accepted optimum blend; maximum synergy occurs with a 50:50 blend, but use generally appears to have shifted from 50:50 blends to aspartame-rich blends in the range 30:70 to 10:90 acesulfame K:aspartame. This may be to take advantage of improved stability of these blends (see Section 4.3.3.2.3 on managing the stability of blends).

4.3.3.2 Aspartame
Aspartame is the generic name for N-α-aspartyl-L-phenylalanine methyl ester. It is composed of two amino acids, L-aspartic acid and L-phenylalanine, joined by a methyl ester link. It was discovered in 1965 by J. Schlatter at the G.D. Searle Laboratories. It is a white crystalline product and its solubility in water is 10 g/l at 20°C; this figure increases at elevated temperatures and in acidic conditions (Ajinomoto Aspartame Technical Bulletin, 2003). It is sparingly soluble in other solvents.

The taste profile of aspartame is similar to sucrose sweetness (Ripper et al., 1985). It is approximately 200 times as sweet as sucrose. It is synergistic with saccharin, cyclamate, stevioside, acesulfame K and many sugars, in particular fructose, but has little sweetness intensity synergy with sucralose.

The maximum use level in soft drinks within the European Union is 600 mg/l, which means that, unlike most other intense sweeteners, it can be used as the sole sweetener in soft drinks.

4.3.3.2.1 Stability. Aspartame is made up of amino acids and, therefore, unsurprisingly degrades under conditions of elevated temperature and extremes of pH. This results in a corresponding loss of sweetness. The critical factors that dictate the rate of degradation of aspartame in soft drinks are pH, temperature, moisture and time.

4.3.3.2.2 Managing stability of aspartame-containing beverages

\textit{pH} The optimum pH for aspartame stability is 4.3. The closer the soft drink formulator can get to this level the better. In practice, many beverages containing aspartame have a pH in the 3.0–3.7. Small changes in pH level to get closer to the pH optimum can have a very significant impact on stability, as can be seen from Figure 4.2.

\textit{Temperature} The effect of ultra-high temperature (UHT) treatments on aspartame stability is minimal, with losses in the range 0.5–5% (Shazer et al., 1988).

4.3.3.2.3 Optimising stability of aspartame/acesulfame K blends. Drinks that use aspartame blends can often achieve excellent stability, if formulated
correctly. The data plotted in Figure 4.3 shows the synergy between aspartame and acesulfame K. Take two products:

Product (a) is a 50 : 50 blend of aspartame : acesulfame K to take maximum advantage of the synergy between the two sweeteners. The total sweetener level is 280 ppm.

Product (b) is a 90 : 10 blend of aspartame : acesulfame K to give equivalent sweetness to (a). The total sweetener level is 440 ppm.

Over time, aspartame degrades, and when the products are analysed again product (a) now contains a blend of 141 ppm acesulfame K and 111 ppm aspartame and will have lost a significant amount of sweetness due to

(1) loss of aspartame sweetness through degradation;
(2) loss of synergy, as we have moved down the synergy curve.

Product (b) is also re-analysed. Again, it has lost some aspartame and contains 50 ppm acesulfame K and 311 ppm aspartame, but the impact on perceived sweetness is lower because, although sweetness has been lost due to aspartame degradation, this has been compensated for by greater synergy between acesulfame K and aspartame. In this instance, we are moving up the synergy curve as aspartame degrades.

In summary, to maximize the stability of aspartame/acesulfame K blends in soft drinks, formulate on the right-hand side of the synergy curve. This is also an example of how the analysis of sweetener levels in a soft drink may not always give an accurate reflection of the perceived sweetness/acceptability of a drink.

In dry beverages aspartame is stable for several years. Analysis of aspartame is generally by HPLC (MacArthur et al., 2002).
4.3.3.2.4 Metabolism. Aspartame is metabolised by the body into its two constituent amino acids and methanol. These hydrolysis products are handled by the body in the same way as the aspartic acid, L-phenylalanine and methanol from other commonly consumed foods. It adds nothing new to the diet.

4.3.3.2.5 Phenylketonuria. Phenylketonuria (PKU) is a genetic condition whose sufferers have an inability to metabolise the essential amino acid L-phenylalanine. Their intake of this amino acid from any source (e.g. milk, vegetables, meat and aspartame) must be strictly controlled from birth to adulthood. It is for this reason that an aspartame-containing product requires the statement that it ‘contains a source of phenylalanine’ on the pack.

Aspartame is non-cariogenic and, like all amino acids and protein products, has a caloric value of 4 kcal/g. However, as the level at which it is used is so low, its contribution to the caloric value of soft drinks is negligible.

4.3.3.2.6 Regulatory. Aspartame is permitted across the world in all major markets. It has an ADI of 40 mg/kg bw, which is significantly higher than other sweeteners. It is ironic that, historically, this sweetener has been the subject of allegations about adverse health effects. Evidence put forward has been largely anecdotal and picked up and promoted via the internet or the lay press. Scientifically controlled peer-reviewed studies have consistently failed to link aspartame consumption, even of abuse levels, to adverse health effects. The most recent review, of over 500 studies and reports about aspartame conducted by the Scientific Committee on Food (SCF), concluded that

Aspartame is unique among the intense sweeteners in that the intake of its component parts can be compared with intakes of the same substances from natural foods. It is clear that the consumption of aspartame represents only a minor source of aspartic acid, phenylalanine or methanol in the diet. (SCF, 2002)

4.3.3.2.7 Salt of aspartame and acesulfame. A salt of aspartame and acesulfame is now available. The product is a chemical combination of aspartame and acesulfame in a ratio of 64 : 36 on a weight basis. This product was given 2 years’ temporary national approval in the United Kingdom (Statutory Instrument 2003 number 1182). It also has temporary approval in The Netherlands (Staatscourant, 17 July 2002), and it can be used in the United States, Canada, China, Mexico and Russia. In 2004, amendment of the EU Sweetener Regulation saw extension of the approval to all EU markets. In solution, the salt breaks up to form aspartame and acesulfame. The relative sweetness is 350 (HSC, 2003).

4.3.3.3 Alitame
Alitame is the generic name for L-α-aspartyl-N-(2,2,4,4-tetramethyl-3-thetanyl)-D-alaninamide hydrate. Pfizer patented the sweetener in 1980 (Pfizer, 1980). It is a white, non-hygroscopic crystalline powder with good solubility in
water. Alitame is approximately 2000 times as sweet as sucrose (10% equivalent). The taste quality is similar to that of sucrose and aspartame.

Alitame is an amino acid derivative and, therefore, not completely stable. It does hydrolyse in acid conditions, but is more stable than aspartame under certain conditions (Pfizer, 1987). Alitame is partially metabolised and absorbed in humans and is excreted as a mixture of its metabolites and unchanged alitame (Pfizer, 1987).

The caloric value of alitame is 1.4 cal/g. JECFA have assigned an ADI of 0.1 mg/kg bw. The Committee on Toxicology (COT) ADI is 0.3 mg/kg bw. Alitame is currently permitted for food use in China and Australia. Submissions for approval have been made to the FDA. In Europe, a submission will be made to the EU Commission and also temporary approval will be sought in the United Kingdom via the Food Standards Agency (Koivistoinen, 2003).

4.3.3.4 Cyclamate

With the general name of cyclohexylsulphamate, this sweetener was discovered in 1937 by Michael Sveda at the University of Illinois. The sodium salt is the most commonly used form. It is a white crystalline salt with good solubility. The relative sweetness of cyclamate is comparatively low, at approximately 35, in most food systems (Bakal, 1983). The taste quality of cyclamate as a sole sweetener has a slow onset time and can have a sweet/sour aftertaste at high concentrations (Franta et al., 1986). Sweetness quality is greatly improved in combination with other sweeteners. Cyclamate is synergistic with acesulfame K (Von Rymon Lipinsky, 1985), aspartame (Searle, 1971), saccharin (Von Rymon Lipinsky, 1987) and sucralose (Tate & Lyle Plc, 2002).

Cyclamate is stable under conditions likely to be encountered in soft drinks, that is, pH range 2–7, pasteurisation and UHT treatments. Analysis is usually using HPLC. Owing to differences in chemistry between cyclamate and other intense sweeteners, cyclamate requires derivatisation before analysis by HPLC (MacArthur et al., 2002).

Cyclamates are non-cariogenic and non-caloric (Bakal, 1983). The majority of people metabolise less than 10% of cyclamate intake. However, approximately 47% of the population have the ability to metabolise 20–85% cyclamate (via the gut microflora) into cyclohexylamine, in which form it is excreted (Kasperson & Primack, 1985; Renwick, 1985; TNO BIBRA, 2000).

Historically, cyclamate was used in soft drinks in the United States from 1958 and in the United Kingdom from 1964, in combination with saccharin. In 1969, it was banned in the United States for use in general purpose foods on the basis of studies suggesting it may cause bladder tumours in laboratory animals. Several other countries, including the United Kingdom, followed suit. The ban on cyclamates was controversial and the original rat study has been heavily criticised. Subsequent studies on safety have implicated cyclohexylamine (the
principal metabolite of cyclamate) in high blood pressure (Eichelbaum et al., 1974), testicular atrophy in rats (Mason & Thompson, 1977) and cancer promotion (Hicks, et al., 1975).

The FDA has, so far, refused to lift the ban on cyclamate, despite several petitions from Abbot Laboratories. Cyclamate is permitted in the European Union and came back into use in the United Kingdom via the harmonised EU Sweetener Regulations 1991. Use of cyclamate in the UK soft drinks industry is almost non-existent 10 years after its re-approval.

Cyclamate is permitted for use in over 25 countries. JECFA tripled the ADI of cyclamate to 0–11 mg/kg bw in 1982. In 2001, this was reduced to 0–7 mg/kg bw due to concerns regarding overconsumption by some population groups. The EU maximum use level in soft drinks is 250 mg/l. Therefore, cyclamate can contribute only a relatively small proportion of the total sweetness of a soft drink.

Cyclamate is used extensively in some European countries, usually at low levels as part of three- or four-way blends in combination with aspartame, acesulfame K and saccharin.

4.3.3.5 Neohesperidin Dihydrochalcone

Neohesperidin dihydrochalcone (NeoDHC) is a phenolic compound prepared from the bitter citrus flavanones naringin and neohesperidin (Horowitz & Gentili, 1985). NeoDHC is a white solid with solubility in water of 0.5 g/l, which increases with temperature, but as use level is low, sufficient for most applications.

The relative sweetness of NeoDHC is quoted at 250–1300 depending on concentration (Horowitz & Gentili, 1985). Its taste is characterised by a slow onset time and a lingering liquorice aftertaste. This is a major limitation on its use in soft drinks applications. However, NeoDHC has some interesting taste-masking properties and has been used at very low levels (6–12 ppm) to mask bitterness in fruit juices (Horowitz and Gentili, 1985).

The stability of NeoDHC is good under many of the process and storage conditions that exist in soft drinks production. In the European Union it is permitted via the 1994 Sweetener in Food Regulation, with a maximum use level in soft drinks of 30 mg/l. It is assigned E-number 959. It is not permitted for use in the United States. Use in soft drinks is limited by its taste profile.

4.3.3.6 Sucralose

Sucralose is the general name for 4,1’,6’-trichloro-4,1’,6’-trideoxygalactosucrose, a chemical derivative of sucrose. It is a white crystalline powder with good solubility and shows very good stability in wet and dry forms across a wide range of processing and storage conditions. At elevated temperatures, slow decomposition can occur, resulting in a colour change from white to brown (Jenner, 1988).
The sweetness quality of sucralose is similar to that of sucrose. Sucralose exhibits synergism with acesulfame K, cyclamate, saccharin and stevioside (Tate & Lyle Plc, 1985a, 1986). It is not synergistic with sucrose and shows little sweetness intensity synergy with aspartame. However, the sweetness quality of sucralose can be improved in cola by blending with aspartame (Tate & Lyle Plc, 1985b).

Sucralose is not metabolised by mammalian species and is poorly absorbed by the body. JECFA has assigned an ADI of 15 mg/kg bw. Sucralose was approved in the United States in April 1998 for use in a variety of food applications, including soft drinks. In August 1999, this approval was extended to full-category ‘GMP’ approval. In the United Kingdom, it was granted a temporary approval on 15 March 2002 (UK Statutory Instrument 379). In 2004, sucralose was added to the EU list of permitted sweeteners.

To date, the use of sucralose in soft drinks in the markets in which it is approved has been relatively limited. There have been a number of launches in the United States involving small- to medium-sized brands. In the United Kingdom, at the time of writing, there are only a handful of relatively minor soft drinks that have converted to sucralose.

4.3.3.7 Neotame

Neotame is the generic name for N-[N-(3,3-dimethylbutyl)-L-α-aspartyl]-L-phenylalanine-1-methyl ester. It is a derivative of aspartame and is a white powder. It is approximately 8000 times sweeter than sucrose and is, therefore, used at extremely low levels in soft drinks (e.g. 6 ppm in cola) (Prakash et al., 2002).

Neotame is characterised by an intensely sweet taste with a lingering liquorice back-taste, which is more noticeable when it is used as a sole sweetener or at high levels. Combinations with other bulk and intense sweeteners improve the taste quality. Generally, acceptable products can be made without major reformulation using up to 25% of sweetener provided by neotame (The NutraSweet Company, 2003).

Neotame is an amino acid derivative and is, therefore, hydrolysed under conditions of low or high pH. Its stability will be a function of pH, temperature and time. The optimum pH range is similar to that for aspartame: pH 3.2–4.5. In dry form neotame is stable. Products containing neotame and processed by high-temperature short-time (HTST) do not show significant losses to degradation of neotame (The NutraSweet Company, 2003).

Neotame is reported to have some flavour-enhancing properties, for example, of mint. It is rapidly metabolised by the body, yielding de-esterified neotame and small amounts of methanol. It does not accumulate in the body and is eliminated via the urine and faeces. Owing to its structure, l-phenylalanine is not a metabolite and, therefore, a PKU (phenylketonuria) statement is not required. No ADI has been assigned (The NutraSweet Company, 2003).
In the United States the FDA granted general use approval for neotame as a sweetener and flavour enhancer in July 2002. At the time of writing it is also approved in Australia, New Zealand, China, Mexico, Costa Rica and Puerto Rico. Neotame was submitted to the EU SCF in 2001 for evaluation and to date no evaluation has been published. Poland has granted temporary approval for neotame and it is also approved in the Czech Republic and Romania.

4.3.3.8 Saccharin
Saccharin is the generic name for 1,2-benzisothiazolin-3-one-1,1-dioxide and has been used for over 100 years, since its discovery by Fahlberg and Remsen in 1879 and the first production patent granted in 1885. Saccharin is a white crystalline product; the sodium salt of saccharin is the commonly used form in the soft drinks industry. Solubility is excellent and stability under food and drink processing conditions is also excellent.

Saccharin has a relative sweetness of 300–500. The taste profile is marred by a bitter metallic aftertaste, which is more pronounced at high concentrations. As with the bitter back-taste of acesulfame K, some individuals appear to be more sensitive to this than others (Bartoshuk, 1979). Several products have found use as masking agents for saccharin’s bitter taste, including fructose and gluconates (US Patent, 1979), tartarates (British Patent, 1975), ribonucleotides (Bakal, 1987), sugars, sugar alcohols (Hyvonen et al., 1978) and other intense sweeteners.

Synergism occurs with fructose (Hyvonen et al., 1978), aspartame, cyclamate (Bakal, 1987) and sucralose (Tate & Lyle Plc, 1986). Negative synergy (i.e. suppression) occurs with acesulfame K blends. Analysis of saccharin is usually done using HPLC (Hahn & Gilikson, 1987) or spectrophotometric methods (Ramappa & Nayak, 1983).

Saccharin is excreted from the body unchanged in the urine (Renwick, 1985). Saccharin is approved widely throughout the world for food use. However, there have been several attempts to ban it due to clinical evidence based on laboratory animals indicating that high doses may cause certain cancers (Berbanic, 1986; SCF, 1984; Taylo & Weinberger, 1980) For this reason, in the United States, products containing saccharin used to have a warning printed on the packaging that saccharin had been shown to cause cancer in laboratory animals. In 2002, the requirement to put this warning on packs was withdrawn by the FDA. In Europe, saccharin has been assigned an ADI of 2.5 mg/kg bw and has a maximum use level of 80 mg/l in soft drinks. It is permitted via the EU Sweetener in Food Regulations 1996.

4.3.3.9 Stevioside
Stevioside is used as a sweetener in Far Eastern markets and in some South American countries. It is extracted from the leaves of Stevia Rebaudiana
Bertoni, a plant native to Paraguay and now commercially cultivated in Asia and South America. Several extracts from the Stevia plant are available which contain different levels of stevioside and also other sweet compounds (rebau-diosides, dulcosides). This inconsistency of extracts is probably the reason much variation exists in the data about stevioside.

Pure stevioside is a white hygroscopic powder (The Merck Index, 1976) and commercial extracts vary from cream to tan powders. The solubility of pure stevioside in water is 1.2 g/l (The Merck Index, 1976). Commercial extracts have solubilities that range from 300 to 800 g/l (Stevia Corporation, 1986). The relative sweetness of stevia extracts varies from 15 to 300 (O’Donnell, 1983; Richard, 2002; Tunaley et al., 1987). The taste of stevioside is characterised by a lingering sweetness and liquorice, bitter off-taste (O’Donnell, 1983). This limits its commercial application and it is generally not used as a sole sweetener in most applications.

Various other compounds have been shown to improve the taste profile of stevia extracts, including aspartame (Chang & Cook, 1983), fructose (Pilgrim & Schultz, 1959), histidine and sucralose (Tate & Lyle Plc, 1986). The stability of stevioside extracts is generally good. Long-term stability tests in carbonated beverages indicate no degradation over 5 months at 22°C (Chang & Cook, 1983). Analysis is generally done using HPLC (Chang & Cook, 1983).

The metabolism of stevia and stevia extracts has been the subject of much discussion. The available data are inconsistent and it is unclear whether steviol, the aglycone portion of stevioside, is generated in the gut. Steviol produces a mutagen (Phillips, 1987). The generation of steviol has been demonstrated in vitro and in vivo in rats (Phillips, 1987).

The regulatory position of stevioside varies in different regions of the world. Japan is the main market for stevioside and consumes 90% of the world’s supply of stevia leaves (Richard, 2002). Stevioside is used in Japan in a variety of applications, including soft drinks. In other markets, the use of stevioside, if permitted at all, is limited to supplements. In the United States, the FDA issued an import alert in May 1991 blocking the import of and sale of stevia products, following the results of a preliminary mutagenicity study. In 1995, the FDA revised the import alert to allow the sale of stevia and its extracts as a food supplement, but not as a sweetener. It currently does not have GRAS status and is considered to be an ‘unsafe food additive’ (Richard, 2002).

In the European Union there have been several petitions to approve stevia and its products. In 2000, the EU Commission refused marketing authorisation for Stevia rebaudiana Bertoni plants and dried leaves as a novel food or novel food ingredient (Official Journal of the European Communities, 2000). In October 2003, the SCF rejected a request to re-examine the restrictions on the uses of extracts of stevia. Its comment, after thoroughly examining the evidence, was that ‘the committee has serious doubts about the safety of stevioside and does not consider it acceptable for use in food’ (European Parliament, 2003).
JECFA reviewed stevioside in 1998 but could not quantify an ADI because of inadequate data on its safety and composition (WHO, 1998). Approval in the major soft drinks markets of the United States and the European Union looks unlikely until more data that would reassure regulators that it is a safe substance are made available.

4.4 New sweeteners/bulking agents used in soft drinks

The increased nutritional awareness of consumers, together with the desire to make soft drinks more nutritionally dense and, therefore, have a healthier consumer image, has given rise to the development and use in soft drinks of other carbohydrates with specific physiological attributes as partial sugar replacers. These physiological attributes include beneficial effects on gut health and increased levels of dietary fibre. There follows a brief review of some of the potential new ingredients. General properties are summarised in Table 4.1.

4.4.1 Inulin

Inulin is extracted commercially from chicory root, which has a high inulin content (15%). Extraction procedures are parallel to those used to extract sucrose from sugar beet. Inulin is a linear β2-2 fructans, a mixture of oligo-saccharides and polymers in which the number of monomers (fructose) refers to the degree of polymerisation (DP), which varies from 2 to approximately 60 units. When hydrolysed, inulin produces fructo-oligosaccharides (FOS) with different degrees of polymerisation. Generally, fructo-oligosaccharides have DP values from 3 to 5 and inulin an average DP value of 10, although it may be much higher (Roberfroid, 2002). The DP does affect the physiochemical and physiological attributes of this product.

Inulin is soluble in water (maximum 10% at room temperature) and forms a gel-type structure. It does hydrolyse in acid conditions over time to produce fructose. It is heat stable. In soft drinks it can produce similar mouthfeel and technical properties to glucose syrup.

Inulin has no sweetness and possesses a bland taste. Physiologically, inulin behaves as a dietary fibre. At relatively high dose levels (15–40 g/day) it can have a prebiotic effect (i.e. it can selectively promote the growth of beneficial bacteria in the colon) and at high dose levels it may also have a laxative effect (Kolida et al., 2002). This is dependent on the specific composition of the product and the degree of polymerisation, which can vary. The caloric value for inulin is 1 kcal/g. Its use in soft drinks is as a fibre source, prebiotic and partial sugar replacer.
4.4.2 Fructo-oligosaccharides/oligofructose

FOS and oligofructose are fructose oligomers that are either produced by enzymic conversion of sugar or extracted from chicory, as inulin, and then hydrolysed. These products behave as soluble fibres and prebiotics. In acid conditions, they can hydrolyse, but are usually sufficiently stable for short-shelf-life juices, near-water products with low acid levels or powdered soft drinks. Prebiotic activity varies with preparation and required daily dose can be as low as 2.5–5.0 g/day for shorter chain FOS preparations (DP 2–4). Some positive effects on magnesium absorption and calcium absorption (in some populations) have also been shown (Beghin Meiji, 2001).

Products are available in dry or syrup form. They have a lower sweetness than sucrose, RS = 0.3–0.6. The caloric value in the EU is 2 kcal/g. They are relatively hygroscopic and have good solubility. Use in soft drinks and juice products is as a sugar replacer, soluble fibre and prebiotic.

4.4.3 Polydextrose

Polydextrose was the first of the ‘new generation’, healthier speciality carbohydrates to be used in soft drinks. In the 1980s, Otsuka in Japan launched Fibermini, which was in effect a flavoured polydextrose solution aimed at the health drink market as a fibre supplement.

Polydextrose was developed by Pfizer and is now marketed by Danisco under the Litesse brand. Polydextrose is produced from glucose, sorbitol and citric acid and, under tightly controlled processing conditions, a randomised glucose polymer is produced. It is soluble in water, neutral in taste and is available in liquid (70% solution) or dry format, as an amorphous powder or agglomerated granule. It is extremely stable to extremes of pH and temperature.

Due to its viscosity, polydextrose gives good mouthfeel in soft drinks, but does not provide any sweetness (RS = 0). The caloric level is 1 cal/g. It is partially metabolised in the large intestine (and, therefore, independently of insulin) and so is suitable for diabetic and low glycaemic index products. It does not promote tooth decay, as it is not metabolised by oral bacteria.

Polydextrose behaves as a dietary fibre and is approved as a fibre in the United States, Japan and Belgium. Its status as a dietary fibre in the rest of the European Union is currently a little unclear. It is permitted for food use in the United Kingdom under The Miscellaneous Additives Regulations and has the E-number E400.

Prebiotic dose–response studies have indicated 10–12 g polydextrose are required to give a prebiotic response (Zhong et al., 2000).

It is currently used to improve mouthfeel and as a soluble fibre, prebiotic and partial sugar replacer in soft drinks.
4.4.4 Trehalose

Trehalose is a relatively new bulk sweetener with potential for use in soft drinks. It is a di-glucose sugar and it occurs in nature in shellfish and mushrooms, where it confers a degree of protection to plant and animal cells in conditions causing dehydration. This led to its use as a cryoprotectant in freeze-drying systems in the pharmaceutical industry. In food markets, its potential use is as a bulk sweetener. It is manufactured using the Hayashibara patented process using starch as a raw material. The process involves enzymatic conversion and crystallisation to the trehalose dehydrate crystal (LFRA, 2001).

In the European Union, trehalose was approved via the Novel Foods process in 2001. In the United States, it was given GRAS status in 2002. It is also approved for use in Japan.

The trehalose molecule, which is two glucose units joined by an $\alpha,\alpha,1,1$ link, gives a stable non-reducing sugar. It has low hygroscopicity and this may be useful in powdered soft drinks to improve the flowability of dry mixes. It is stable in acid conditions, unlike many sugars, and has been reported to enhance flavour profiles in some systems. Trehalose has a very high glass transition temperature and it is thought that this may be the reason for the interesting protective properties for biological cells under extreme conditions of low temperature and dryness.

Trehalose is metabolised in a similar manner to other sugars, being broken down into glucose in the small intestine and then absorbed like other sugars. Its energy value is 4 kcal/g (17 kJ/g). Absorption of glucose from larger doses of trehalose is slower than from a glucose dose, producing a lower insulin response (LFRA, 2001). This may lead to application in diabetic products and sports drinks. The relative sweetness of trehalose is 0.45 and it may, therefore, it may find application where the technical functionality of sugar is required but not the sweetness. It is less cariogenic than sucrose (Cargill, 2003).

Current use of trehalose in soft drinks is limited.

4.4.5 Tagatose

Tagatose is another potential new addition to the range of sucrose alternatives for soft drinks formulators. At the time of writing, it is not currently permitted in the European Union (approval is expected in 2005) (Eriknauer, 2003). In the United States it was granted GRAS approval in 2001 for use in a range of foods and drinks. Approval is also being sought in Asia and Australasia.

Tagatose is manufactured from lactose using technology patented by Biospherics. Lactose is enzymically converted to glucose and galactose; the galactose is then isomerised to tagatose, which is then purified and crystallised. It is a low-calorie ketohexose reducing sugar which occurs naturally in a polysaccharide gum, from Sterculia setigera.
The solubility and hygroscopicity of tagatose are similar to those of sucrose, but the viscosity of solutions is lower. As a reducing sugar it is less stable in acid conditions and liable to take part in Maillard reactions.

It has been reported to be synergistic with intense sweeteners such as aspartame and acesulfame K and, when used at low levels (0.2%), improves certain flavour profiles (Eriknauer, 2003; LFRA, 2001). The relative sweetness of tagatose is 0.92. On ingestion, 20% of tagatose is absorbed in the small intestine and the rest is metabolised by the microflora of the colon. Dose–response studies indicate a prebiotic effect at 10 g/day (Eriknauer, 2003).

Consumption of tagatose does not lead to sharp rises in blood glucose or insulin levels and it is, therefore, suitable for diabetic or low glycaemic index foods and drinks. The calorie level is 1.5 g/day and it is also non-cariogenic (oral bacteria only very slowly metabolise tagatose). Despite the fact that it is a sugar, and, therefore, should fall outside the FDA definition of tooth-friendly ingredients, the FDA somewhat controversially approved it for use in tooth-friendly products (FDA, 2003).

The year 2003 saw a couple of relatively minor launches of tagatose-containing frozen ‘Slurpee’ type products in the United States.

JECFA has set a temporary ADI of 125 mg/kg bw (Eriknauer, 2003). This is scheduled for review by JECFA in June 2004 (Eriknauer, 2003).

4.5 The future

Soft drinks formulators today have a greater choice of bulk and intense sweeteners than ever before. Optimisation of the taste profile of drinks containing sweeteners has improved significantly over the last 20 years. This may limit the opportunities for some of the newer sweeteners, as additional taste improvement will be incremental, compared with the substantial taste improvements seen in the early 1980s, when several new sweeteners were approved.

However, as global concern regarding obesity and high sugar consumption increases, the market for lower-sugar, lower-glycaemic-load and calorie-controlled products will increase, and it follows that the use of sugar substitutes will increase. The need to optimise the taste and physiological profile of soft drinks to satisfy this market trend will present new challenges to the soft drinks formulator.

References