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# Aspartame: Technical Considerations and Predicted Use

Werner Vetsch

NutraSweet AG, Baarerstrasse 82, 6300 Zug, Switzerland

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*ABSTRACT*

*Aspartame can be used as a safe, low-calorie sweetening ingredient in liquids and drinks, as a high-intensity sweetener in dry mix products, as sugar substitute in table-top sweeteners and in a great number of semi-liquid and frozen products. It will provide a clean, sweet taste without any metallic aftertaste.*

*It can also function as a flavour enhancer in certain applications.*

*Aspartame has 180–200 times the sweetness of sucrose. As a nutritive sweetener with a caloric value of 4 kcal g$^{-1}$ only minute amounts are needed which means that it has virtually no caloric impact on the final product. It is also suitable for diabetics as it is a dipeptide-methyl ester but not a carbohydrate.*

*Aspartame can be used without restrictions in a great number of food applications as an intense sweetener, with the exception of those requiring prolonged high temperature treatment, such as baking or frying, and certain liquid applications in the neutral and alkaline pH range.*

*Aspartame does not provide any bulk, structure, mouthfeel or viscosity. Suitable bulking agents may be used together with aspartame in semi-liquid and solid foods, to substitute for certain bulk properties of sucrose.*

*Aspartame has proved a valuable addition to the fast-growing low-calorie food sector, allowing the formulation of 'light foods' with organoleptic properties very similar to those of full-calorie food products.*

## INTRODUCTION

Acceptance of the new sweetener aspartame by the food and drinks industry has been exceptionally good. Marketed under the brand name of NutraSweet®, this high-potency, low-calorie sweetening ingredient has created considerable interest among industry and consumers alike within a short period of time.*

Public interest, supported by broad media coverage, has led to an intensified search for sugar substitutes and non-caloric sweeteners in recent years. Health authorities also are becoming increasingly concerned at excessive carbohydrate or sugar consumption.

Ideally, high-intensity sweeteners should meet the following standards: be safe, have a clean, sweet taste, be low in calories, be of high sweetening potency, possess reasonable stability, should not promote tooth decay, be realistically priced, be easily metabolized, be nonlaxative and readily available. Obviously meeting all these requirements is a difficult task, and points to the reason for the rather limited number of high intensity sweeteners available. Aspartame is a prime choice among low-calorie sweeteners because it meets the requirements almost ideally.

The trend toward light or calorie-reduced food, such as low-calorie or 'light' soft drinks, sugar-free chewing gums and calorie-reduced yogurts, points to a most interesting growth opportunity within the otherwise slow-growing food industry.

Since aspartame has some very specific characteristics, the food technologist working with this sweetening ingredient should be fully aware of its advantages and limitations before commencing low-calorie development projects.

In this paper some of the technological aspects of this new sweetening compound will be discussed in more detail. The major areas covered will be the composition, metabolism and safety of aspartame, and its properties and applications.

## COMPOSITION, METABOLISM AND SAFETY

Aspartame is a dipeptide of two amino acids, L-phenylalanine as the methyl ester, and L-aspartic acid. It is a substance of intense sweetness and flavour-enhancing properties (Fig. 1). It is made of components identical to those found in nature. One, L-phenylalanine, is an essential amino acid

* NutraSweet is a registered trademark of G. D. Searle & Co.

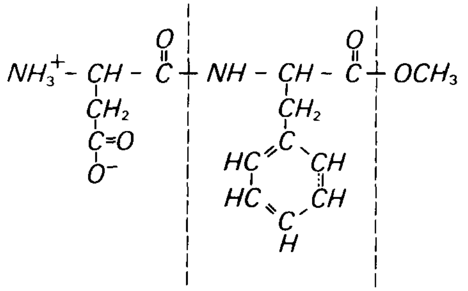

**Fig. 1.** Structural formula of aspartame.

required in our daily diet. Aspartic acid is not essential but is part of all proteins, including those in the human body. Methanol, too is found widely in our food supply. For example, 19 mg aspartame, a quantity of equal sweetness to one teaspoon of sucrose, produces 7·6 mg of aspartic acid, 9·5 mg of phenylalanine and 1·9 mg of methanol. In comparison, 1 glass (250 ml) of milk produces 528 mg aspartic acid and 542 mg phenylalanine (about 60 times the amount provided by aspartame). A glass of tomato juice produces about 47 mg of methanol, an amount equal to that of 25 glasses of a drink sweetened with aspartame.

Metabolism studies have shown that aspartame is metabolized like any other food protein. Digestion converts the sweetener to its basic components: L-phenylalanine, L-aspartic acid, and methanol. The energy yield of 4 kcal $g^{-1}$ is the same as for any protein or carbohydrate.

Aspartame and its conversion products have been extensively investigated and tested for safety in more than 100 studies in man and animals over more than 10 years. It has been reviewed and approved as safe by regulatory authorities in 36 countries, as well as by the Joint Experts Committee of the World Health Organisation (JECFA-FAO/WHO), the Committee on Toxicology for the Ministry of Agriculture, Fisheries and Food in the UK (MAFF), and as recently as 14 September, 1984 by the scientific committee of the Confederation of the Food and Drink Industry of the EEC.

In 1981 the Joint Experts Committee on Food Additives of the FAO/WHO established the following acceptable daily intake levels (ADI) for aspartame and its conversion product (Anon., 1981):

| | |
|---|---|
| aspartame | 40 mg $kg^{-1}$ body weight |
| diketopiperazine | 7·5 mg $kg^{-1}$ body weight |

This indicates that aspartame is one of the most thoroughly tested food additives ever to go through the regulatory process and definitely attests its safety.

Aspartame is not a carbohydrate, and only minute amounts are needed to gain acceptable sweetness levels. The caloric impact is therefore negligible. The sweetener is also suitable for diabetics.

In addition to an almost worldwide approval of aspartame as a table-top sweetener, its use in food and drinks has been permitted in more than 18 countries, among them the USA, Canada, the United Kingdom, Ireland, Belgium, Scandinavia and Switzerland. However, the categories of permitted use may differ from country to country. In view of its broad acceptance in major markets and its excellent safety record additional approvals in Europe are imminent.

## PROPERTIES

The technological advantages of aspartame can be stated as follows:

clean taste, no bitter aftertaste;
enhances and extends flavours;
has the potential to reduce the amount of sugars and sweeteners in products;
can reduce package weight and size;
may be combined with sugars and/or sweeteners;
reduces calories.

### Sweetness character

Aspartame is a white, odourless, crystalline powder. It has a clean, sweet taste and a sweetness potency of 180–200 times that of sucrose (Table 1). It adds not only good taste but also enhances and prolongs certain fruit flavours in foods. Numerous studies on the function of aspartame in different systems have been made by both independent and industrial research organisations, using a variety of accepted sensory evaluation techniques. The data collected to date support claims that the flavour and taste profile of aspartame is very close to that of sucrose (Beck, 1974; Larson-Powers & Pangborn, 1978*a*, *b*; McPherson *et al.*, 1978; Baldwin & Korschgen, 1979; Cloninger & Baldwin, 1979). However, its sweetness develops more gradually and persists slightly longer than that of sucrose.

**TABLE 1**
Aspartame (APM): Physico-chemical Properties

| | |
|---|---|
| Chemical name | N-L-α-Aspartyl-L-phenylalanine-1-methyl ester, APM |
| Chemical formula | $C_{14}H_{18}N_2O_5$ |
| Molecular weight | 294·31 |
| Color | White |
| Odor | None |
| Form | Powder |
| Taste | Clean, sweet |
| pH (0·8% solution) | 4·5–6·0 |
| Assay (dried basis) | 98·0%–102·0% |
| Diketopiperazine | No more than 1·5% |
| Specific rotation (dried basis) | $[\alpha]_D^{20}$: + 14·5°–16·5° |
| Melting point | 246–247 °C |
| Loss on drying (105 °C, 4 h) | No more than 4·5% |
| Sulfated ash | No more than 0·2% |
| Heavy metals | No more than 10 ppm |
| Solubility | Slightly soluble in water |
| | Sparingly soluble in alcohol |
| Sweetness potency | 180–200 times sucrose |

Sucrose, of course, imparts other qualities than sweetness alone—bulk, structure, texture, viscosity, moisture retention, caramelization, and ability to form a glaze and protection against spoilage being among them.

## Sweetness intensity

The relative sweetness, or potency, of aspartame varies depending on the food system it is used with. More potent at lower concentrations, it tends to be less intense in chilled products. The product type, formulation, pH and flavour also have some influence (Cloninger & Baldwin, 1974). In water, a sweetness potency of 400 at the threshold level has been determined. At a sweetness isosweet to 10% sucrose, its potency declines to 133 (Beck, 1974). By contrast, in lemonade the potency of aspartame increases to 180 at a sweetness level equivalent to 11% sucrose.

This clearly indicates that the amount of aspartame required in low-calorie formulations cannot be determined by simple extrapolation from the sugar content alone. The frequently quoted sweetness potency of 180–200 times that of sucrose should be understood as a general guideline only. The need for bulking agents with aspartame is obvious in all semi-solid and solid food formulations. The ideal bulking agent should possess sucrose-like properties, be inexpensive, have good intestinal tolerance and be low- or non-caloric. None of the currently-permitted sugar substitutes meets all these requirements, but bulking agents such as polydextrose, malbit, palatinit, lycasin, the various polyols, fructose, maltodextrins, whey powder or combinations thereof, depending on the functional properties required, can be recommended in combination with aspartame.

## Reduction of sugars and sweeteners in products

Due to the reduction of bulk provided by sugar, it is quite feasible to obtain a favorable change in the ratio of ingredients by reduction of 'empty calories' and increase of functional or nutritious components, as can be demonstrated by the following example of aspartame-sweetened yogurt formulations (Table 2).

**TABLE 2**
Comparison of Nutritional Values of Aspartame- and Sucrose-Sweetened Yogurt

| | *With aspartame* | | *With sucrose* | | *Difference* | |
|---|---|---|---|---|---|---|
| | *Strawberry* | *Blueberry* | *Strawberry* | *Blueberry* | *Strawberry* | *Blueberry* |
| Caloric value (kcal per 100 g) | 50 | 45 | 90 | 96 | −44 % | −53 % |
| Carbohydrate (%) | 5·9 | 4·9 | 15·9 | 18·4 | −63 % | −73 % |
| Protein (%) | 5·4 | 5·4 | 4·6 | 4·3 | +17 % | +26 % |
| Fat (%) | 0·57 | 0·42 | 0·87 | 0·56 | −35 % | −25 % |

## Reduction of package weight and size

An appreciable reduction of package size and weight can be achieved by using intense sweeteners. For example, in dry-mix beverage formulations with a high sucrose content, up to 93 % weight can be reduced. In addition, a caloric reduction of about 90 % can be achieved.

Spray-dried and/or agglomerated, aspartame-presweetened, instant preparations of high potency, such as iced-tea, calorie-reduced cocoa mixes or instant coffee powders, are just a few examples of products which can be made.

The economic benefits of package size reduction by use of highly concentrated products are obvious for both manufacturers and distributors. Equally important is that sucrose intake can effectively and conveniently be reduced, e.g. aspartame-presweetened coffee powder.

Of course, in order to obtain marketable products, highly concentrated products must be diluted with suitable carriers, or the bulk density must be adjusted by spray-drying or agglomeration.

## May be combined with sugars and/or intense sweeteners

Aspartame may also be combined with carbohydrates such as sucrose, dextrose, and fructose, and intense sweeteners such as saccharin to produce a broad variety of low-calorie or calorie-reduced products. Regulations, however, may differ from country to country.

## Reduces calories

The intense sweetness of aspartame permits food products to be substantially reduced in calories. On the basis of a sucrose consumption of 149 g $day^{-1}$ per person, calculated at 4 kcal $g^{-1}$, the typical intake would amount to 596 kcal $day^{-1}$. However, the same sweetness could be provided with only 0·8 g aspartame, thus providing only 3·2 kcal $day^{-1}$, a caloric intake which is negligible by most people's standards.

## Synergy

Aspartame in combination with other sweeteners can act synergistically. Synergy with saccharin may be as high as 50% and, if nutritive and non-nutritive sweeteners can be blended, can approach 23% with sucrose and 35% with dextrose (Beck, 1978). The synergistic and flavour-enhancing properties of aspartame also have some influence on other ingredients.

## Solubility

The solubility of aspartame in water is a function of pH and temperature. Maximum solubility is at pH 2·2. Minimum solubility is at its isoelectric point, or pH 5·2.

Aspartame's tendency to form soluble salts at pH values below the isoelectric point improves the rate of solubility considerably. Improved solubility of aspartame salts, such as dipeptide sweetener sulfates, has been reported (Tsan & Young, 1983).

For optimum rate of dissolution, it is advisable to use water at an elevated temperature of approximately 40 °C and at pH 4. Loss of sweetness due to longterm storage is negligible, since it takes 22 days to reach a 20 % decomposition under these conditions.

In ethanol, aspartame is soluble at a rate of 0·4 % at 25 °C. It is virtually insoluble in vegetable oils.

## Stability

Due to its amide and ester bonds, aspartame could be subject to hydrolysis and subsequent loss of sweetness. Aspartame contains an ester linkage that may hydrolyse to the dipeptide, aspartylphenylalanine (AP), or be converted to its diketopiperazine (DKP) under certain moisture, temperature and pH conditions. The DKP ring could, in turn, open to form AP, which could hydrolyze to the individual amino acids (Fig. 2).

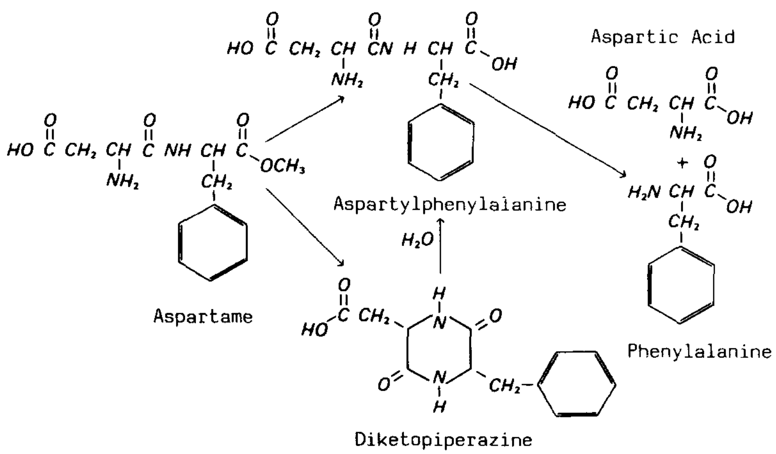


**Fig. 2.** Typical conversion products of aspartame.

The stability of dry aspartame is excellent. Analysis by thin layer chromatography, following a year's storage in a closed system at 40 °C, resulted in a diketopiperazine level of only 1 % and an aspartylphenylalanine content of just 0·5 %.

A study of the decomposition rate at extreme temperatures demonstrated that aspartame is quite stable at 105 °C, and a DKP level of only 5 % was found after 70 h storage at this temperature.

Temperatures well over 150 °C are necessary for breakdown to become substantial. These extreme temperatures are normally encountered only in baking. Regular storage conditions of 20–25 °C and 50 % relative humidity do not cause any stability problems, providing the moisture content of the system is kept below 8 %.

Based on the structural nature of aspartame, its stability in liquids has been questioned by both food technologists and scientists. Under certain conditions, it can break down into flavourless components although, fortunately, these conditions can generally be avoided. Aspartame can remain stable for months, even in liquid systems, providing regular processing and storage conditions are applied.

The stability of aspartame in solution is affected by time, temperature and pH. The pH is of particular importance. Aspartame is most stable in the acidic range of pH 3·0–5·0, with optimum stability at pH 4·3. Fortunately, most liquid food systems and drinks are in this pH range. Outside the optimum pH range of 3–5, stability begins to decrease, particularly in neutral to slightly alkaline solutions.

Expected shelf-life and typical storage conditions should be taken into consideration. For instance, frozen desserts with a pH of 6·5–7, outside the optimum pH range, have shown a stability of at least 6 months, due to the low storage temperature and the limited free moisture. Figure 3 illustrates the stability of aspartame in aqueous buffer solutions at 40 °C and 80 °C. The horizontal lines indicate almost complete stability. The more vertical the lines become, the less stable is the compound. Results

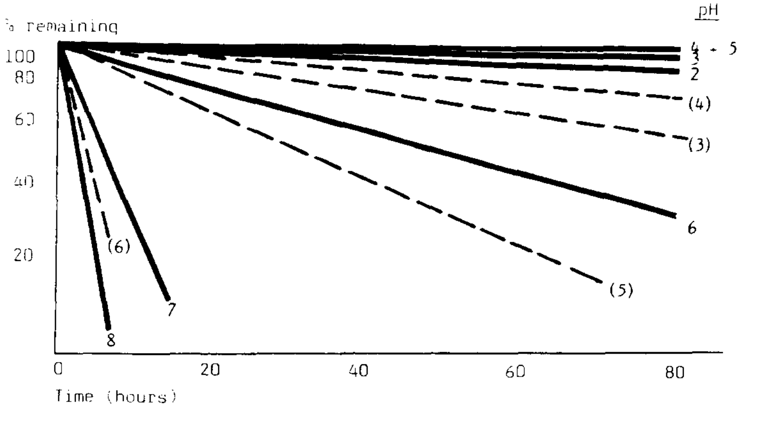


**Fig. 3.** Stability of aspartame in aqueous buffers at 40 °C (——) and 80 °C (– – –).

are similar at 40 °C and 80 °C but most notable is the drop in stability in the neutral range of pH 6–7.

Of course, temperatures of 80 °C are above the level that aspartame-containing products should normally be exposed to, but the 80 °C temperature range is of particular interest since it approximates to the conditions of high temperature-short time (HTST) pasteurization. Decomposition of aspartame by ultra high temperature (UHT) processing, as used for aseptics, can be ignored since the processing time is too short for substantial degradation to take place.

## APPLICATIONS

Since aspartame is a relatively new sweetener with a rather short history in terms of regulatory approvals and permitted food applications, any reference to current categories of use are temporary, with new applications developing continuously.

Table 3 gives an indication of the many food applications available for aspartame. Listed in the 'current' column are products actually on the market, and in the 'potential' column are products in the development stage or those not yet permitted by regulatory authorities.

In reviewing the large number of applications, the following brief discussion of the major product groups should give an indication of the potential and also of the limitations of aspartame.

### Carbonated beverages

One of the major uses of aspartame is in the low-calorie or 'light' soft drinks segment of the beverage industry. Depending on formulation, processing and storage conditions, a progressive loss of the sweetener through degradation can be noticed. The loss is predictable, though, and is a function of pH, temperature and time.

Improvement of the stability of aspartame in solution by means of aspartame–cyclodextrin–sucrose fatty acid compounds has been reported (Ojima *et al.*, 1983). Aspartame can be utilized in carbonated beverages, squashes and still drinks, assuming careful formulation, optimum processing conditions and distribution channels are used.

The ultimate and deciding factor for the evaluation of aspartame in

**TABLE 3**
Aspartame—Food Applications

| *Products* | *Applications* | |
|---|---|---|
| | *Current* | *Potential* |
| Sugar substitutes (tablets, granules, 'spoon-for-spoon' powder, liquids) | × | |
| Carbonated soft drinks | × | |
| Squashes | × | |
| Jams/jellies | × | |
| Breakfast cereals | × | |
| Chewing gums | × | |
| Instant presweetened tea, coffee, cocoa | × | |
| Fruit flavoured drink mixes | × | |
| Hot chocolate mix | × | |
| Fortified flavourings for milk | × | |
| Pudding mixes (cold/boiled) | × | |
| Gelatin dessert mixes | × | |
| Cheesecake mixes | × | |
| Creme filling powder | × | |
| Plain and fruit yogurt | × | |
| Frozen dairy desserts (non-standardized ice cream, ice milk) | × | |
| Refrigerated still beverages | × | |
| Confectionery pastilles/drops | × | |
| Topping/frosting/coating mixes | × | |
| Dry mixes for catering/food services/dairy/bakery/beverage industries | | × |
| Chocolate/candy bars | | × |
| Confections/marshmallows, jellies, dragées, tablets | | × |
| Canned/bottled fruit juice drinks | | × |
| Canned fruit | | × |
| Sweetened peanut butter, spreads | | × |
| Syrups for beverages, bakery products | | × |

beverages should be its acceptance by the consumer, largely determined by the sweetness level of the beverage at the time of consumption.

Numerous beverages manufactured with aspartame have shown adequate shelf-life under typical storage conditions. Extensive testing has indicated that a loss of up to 40% of aspartame will be tolerated before beverages are considered unacceptable.

Use levels of aspartame in beverages that will provide acceptable sweetness may vary over a broad range and are dependent on factors such as formulation, pH, shelf-life expectations, processing conditions, distribution and storage, synergy effect and general preference by the consumer. Typical use levels for carbonated beverages are (Homler, 1984):

| | |
|---|---|
| cola, | 550–680 mg liter$^{-1}$ at pH 2·4–3·1 |
| lemon-lime, | 300–600 mg liter$^{-1}$ at pH 3·0–3·1 |
| orange, | 550–900 mg liter$^{-1}$ at pH 3·1–3·4 |

**Table-top sweeteners**

These are available as tablets, granules, 'spoon-for-spoon' powders and liquids. Depending on the type of product, bulking agents or carriers such as dextrose, lactose, sorbitol or maltodextrins are used in the case of spray-dried, low density powders. The relatively small amounts of these carbohydrate diluents do not contribute significantly to the overall carbohydrate intake. A typical use level of aspartame in table-top sweeteners, isosweet to one cube of sucrose (4 g), is 18 mg of aspartame per tablet. Diluted aspartame in granulated or agglomerated form, opens new opportunities in the consumer and food service areas.

**Dry-mix products**

These can be classified into two groups: dry blended products and co-dried products.

Dry blended products, including beverage mixes, desserts, pudding/pie filling mixes, dietetic-fortified formulations, fruit or dairy powder blends, can be formulated in the same way as sugar-containing products. Bulking agents may be utilized as needed. For superior product characteristics, it can be beneficial to change from dry blending to granulation or agglomeration processes.

Co-dried products, such as presweetened instant coffee, instant tea, cocoa and beverage powders, require appropriate carriers to provide bulk, such as maltodextrins or whey, sometimes in conjunction with stabilizers. Depending on the required properties, spray-, drum- and vacuum-drying are the processes of choice.

Due to the short residence time in the high temperature range, aspartame can be co-dried without degradation and significant loss of sweetness. Alternatively it may be added either as the pure compound or as a diluted intermediate to the other ingredients, dried or agglomerated separately.

**Dairy products**

Fruit flavoured yogurts are a most interesting application for aspartame since, due to their composition and acceptance as 'slimming' foods, aspartame can reduce calorie intake by up to 50 % without any sacrifices of sweetness character or intensity.

Stability tests have shown that acceptable sweetness can be achieved under regular storage conditions within the normal shelf-life of the product. A typical level of aspartame in the finished product is 0·07 %.

Frozen desserts, including non-standardized ice-creams, ice milks and sherbets, are other possibilities for the formulation of 'light' products with aspartame. The sweetness stability is quite good, despite a pH outside the optimum range. Low temperature and low free moisture are the main factors favourably influencing sweetness stability.

**Confectionery products**

Another application which has raised great interest is chewing gum. Flavour extension, prolonged sweetness and improved flavour perception are some of the advantages of utilizing aspartame. Sorbitol, mannitol and/or xylitol may be used as bulking agents. Other potential confectionery applications include coated and compressed mint tablets, sugarless gum drops, dragees and candy and bakery fillings based on polyols and/or in combination with sugar, to provide low-calorie sweetness.

**Other products**

Products like jams, canned fruits and refrigerated still drinks can also be formulated with aspartame. However, these products demand not only careful formulation and close process control, but also a re-evaluation of the shelf-life expectations of low-calorie products.

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