Artificial Sweeteners Face Sweet 'n' Sour Consumer Market

The artificial sweetener market continues to expand, with more approved products and stiffer competition.

Pierce Hollingsworth, Contributing Editor

Doctors say having one regular soda is like enjoying liquid candy, “intones Dina Bair, Medical Watch reporter for Chicago's WGN-TV. “In fact, it’s the same as a bag of M&M’s. The problem is on average most people have three sodas a day. That’s three bags of candy. At 250 calories a bag, that means 750 calories. . . .” But that’s just the tip of the iceberg, Bair says, the perils of pop approach the level of a national health scandal, and she says she has sound bites from experts to prove it.

This story was broadcast on May 23, in the midst of sweeps month, when local stations across the nation competed for viewers and the ad revenues that go with them. Food fright is a natural attention grabber. Unfortunately, such stories are often more hype than hard fact, supported by experts who are quick with opinion but short on knowledge. The resulting confusion often has a big impact on consumer behavior and artificial, or non-nutritive, sweeteners are a good case in point.

“Think diet sodas are any better?” Bair asks her audience. “It may say no calories on the can, but your body doesn’t believe it.” Then comes the expert clip featuring Amy Halverson, a surgical oncologist at Chicago's Northwestern Memorial Hospital. “If you drink a lot of the diet soda, your body will learn to metabolize the aspartame, you’ll start to absorb calories from that, and it will start to metabolize that,” she says.

Bair clarifies: “By metabolizing the sugar substitute, your body actually turns it into sugar, which can be stored and eventually turned into fat.”

An astonishing revelation if accurate, but it’s not. Viewers were left
with the disturbing notion that three cans of diet cola containing aspartame might just be the same as three bags of M&M’s.

This rap against aspartame, the leading artificial sweetener in a market of four approved products that includes saccharin, sucralose, and acesulfame K, is not new. The Internet is replete with allegations of health threats, most of which date to the legendary Nancy Markle letter that was originally posted, linked, and e-mailed around the world in 1995. In it, Markle, who has never been identified, connects aspartame to a host of medical conditions. Typical is the statement: “There are 92 documented symptoms of aspartame, from coma to death. The majority of them are all neurological, because the aspartame destroys the nervous system.”

The Markle letter is widely considered the catalyst for a sustained movement that has directly and indirectly fueled considerable media attention, public policy decisions, medical opinion and ultimately, consumer behavior over the last decade. The impact has been felt throughout the artificial sweetener market, which has several new approvals pending. The stakes are high. More than 144 million American adults regularly consume low-calorie, sugar-free products, according to the nonprofit trade organization, the Calorie Control Council. The oldest artificial sweetener is saccharin, 300-500 times sweeter than sugar, which was discovered in 1879. Because it is relatively stable at high temperatures, and inexpensive to manufacture, saccharin has been widely used as a sugar substitute since in the 1950s. In 1977, the Food and Drug Administration initiated a warning label policy in light of inconclusive evidence that the sweetener might cause cancer in high doses. The labeling requirement was rescinded in 2000 when the U.S. Dept. of Health and Human Services released its National Toxicology Report on Carcinogens, which removed saccharin from its list of cancer-causing substances.

The only knock against saccharin presently is its bitter, metallic aftertaste. This property was the reason for aspartame’s quick ascendancy as the number-one-selling low-calorie sweetener soon after its approval in 1981. It is 180 times sweeter than sugar, but breaks down under high temperatures. For that reason, aspartame is most widely used in beverages and tabletop packets. It also has been the most widely studied artificial sweetener, especially in light of the intense criticism it received in the mid-1990s.

The market again expanded in 1988 with the approval of Nutrinova, Inc.’s acesulfame K (Sunett®), which is 200 times sweeter than sugar. It holds up to heat, but has some bitterness. It is used in foods such as gum, powdered drink mixes, tabletop packets (Sweet One), puddings and bake mixes, and yogurt.

The newest approved artificial sweetener is sucralose, 600 times sweeter than sugar. It is non-bitter and approved for use in soft drinks, bakery products, candy, and tabletop packets. It was approved in 1998, with sales initiated by Johnson & Johnson under the Splenda brand in 1999.

During the first quarter of 2002, sales surged 42% compared to the year earlier period. In contrast, sales for Cumberland Packing Co.’s Sweet’n Low, the leading saccharin brand rose 3%, while Equal brand aspartame, now owned by newly created Merisant Co., was down 8%. During the same period, Splenda grabbed 19.4% of the tabletop market, just behind Sweet’n Low at 21.5% and Equal at 30.9%.

Part of this success is due to deft marketing by Johnson & Johnson, a $30-billion consumer products powerhouse. Realizing the negative tide that was eroding confidence in artificial sweeteners back in 1999, particularly aspartame, J&J opted for a stealthy launch. It relied primarily on industrial and Internet sales, thus creating a grass-roots mystique. It also stresses that Splenda is actually made from sugar, a theme that has resonated with wary consumers. The result is a grass-roots network of support that has propelled Splenda’s rapid ascendancy. In addition to the tabletop product, it is found in more than 400 brands, like Diet Rite, Tropicana Twister, Ocean Spray, Swiss Miss, and a wide number of health and fitness foods.

While Johnson & Johnson is hammering away at the artificial sweetener market, it also is growing a category that languished during most of the 1990s due to consumer skepticism and a focus by health professionals on fat and cholesterol. Last year, tabletop sweetener sales grew by more than 10%, while diet soft drinks outsold regular soft drinks, due...
to strong growth by Diet Pepsi, Diet Coke, and Diet Dr Pepper. The category grew 0.7%, while regular soft drinks grew 0.5%, according to Beverage Marketing Corp. Other than Diet Rite, most diet soft drinks are sweetened with aspartame, or a blend of aspartame and saccharin.

Even marginal growth is a positive sign for artificial sweetener companies, due to the intense competition from non-carbonated beverages such as iced tea and bottled water.

It may also signal a tapering off of media criticism such as the WGN-TV report. That’s good news for organizations such as the Calorie Control Council. “The negative press on aspartame was far worse two or three years ago than it is right now, with the exception of the [local television rating] sweeps,” stated Lyn Nabors, CCC’s executive vice president. She stressed that most of the bad press is based on recycled Internet data that have been refuted by independent research, including FDA studies. “The original Markle e-mails are still in circulation. They just rehash the same old thing.”

Nabors also is encouraged by the renewed emphasis by health professionals on the role of calories in controlling obesity. “They’re no longer holding diet foods responsible for weight gain. For so long they stressed fat intake and didn’t really talk about calories. Now health professionals are admitting they made a mistake—the bottom line is calories in, calories out.”

Nabors stressed that obesity is a serious health issue in America today. This, combined with a strong scientific foundation for the safety of approved artificial sweeteners should bode well for the market.

In addition, several new sweeteners are being reviewed by FDA, including aspartame derivatives neotame and alitame, as well as cyclamate, which was widely used in low-calorie and diet foods and beverages until it was banned in the U.S. in 1970. It is widely used in the European Union, Canada, and most of South America, and subsequent testing has reaffirmed the product’s safety. “It’s not a priority with FDA,” Nabors said. “It’s hard to get attention where we want it, but we’re working on it.”

Even without cyclamate, the artificial sweetener market will continue to expand, with more approved products and stiffer competition. Already, competitors are beginning to seek out and dominate lucrative niches. Merisant, for instance, is aiming Equal at the aging baby boomer market, battling middle-aged spread and diabetes. It is running ads in Diabetes Digest and older demographic editions of Readers Digest and TV Guide. Meanwhile, Johnson & Johnson continues to shift from stealth marketing to a mainstream appeal to the youth market. Last year it ran a $30 million ad campaign for the brand, which featured soccer star Mia Hamm as a spokesperson.

Soft drinks may become the next battleground. Despite Internet rumors, weird science, and the media shock stories, diet and health conscious consumers seem willing to satisfy their sweet cravings with artificially sweetened, low-calorie foods and beverages. Says Nabors, “The consumer is getting a little more savvy.”
Sweet Choices: Sugar Replacements for Foods and Beverages

Food technologists have a variety of sweeteners to choose from to replace sugar, completely or partially, in foods and beverages. Here’s a rundown of currently available choices.

Lyn O’Brien Nabors

Food technologists now have more sweeteners from which to choose than ever before. With the obesity epidemic and the public attention it currently receives, plus the increasing interest in foods with added benefits, sweeteners that allow for consumer-appealing labeling are of particular interest.

These sweeteners fall into two basic categories: those which are essentially calorie free, often referred to as low-calorie or intense sweeteners, and those which are significantly reduced in calories, which may be referred to as reduced calorie-sweeteners, bulk sweeteners, or sugar replacers. These sweeteners when used alone or in combination may permit such labeling as “low-calorie,” “reduced-calorie,” “light,” “sugar-free,” and “does not promote tooth decay.”

The ideal sweetener does not exist. It would be at least as sweet as sucrose and provide the same properties to a product as sucrose, with processing parameters similar to those of sucrose so that existing equipment can be used. It would be colorless, odorless, and noncariogenic, with a clean, pleasant taste, and have immediate onset and not much lingering. Solubility and stability are important. The ideal sweetener must be compatible with a wide range of food ingredients because sweetness is but one element of a complex food flavor system. Even sucrose is not perfect, being unsuitable for some applications.

There are therefore real advantages to having a number of sweeteners available. With several available, food manufacturers can use sweeteners in the applications for which they are best suited, and limitations of individual sweeteners can be overcome by using them in blends. Most sweeteners, including the polyols, are synergistic, so the sweetness of sweetener blends is greater than the sum of the individual parts. In addition, there is considerable research, including a soon-to-be-published study by Duke University’s Susan Schiffman, demonstrating that blends of multiple sweeteners present improved flavor profiles.

The first commercial sweetener blend was saccharin and cyclamate. The primary advantage of this blend was that saccharin (300 times sweeter than sucrose) boosted the sweetening power of cyclamate (30 times sweeter than sucrose), while cyclamate masked the aftertaste some people associate with saccharin.

Today, blends are frequently used. For example, in the United States, diet fountain soft drinks are generally sweetened with a combination of aspartame and saccharin, while in other parts of the world soft drinks may contain as many as four sweeteners. Sugar-free gums and candies contain combinations such as saccharin/sorbitol and aspartame/potassium/isomalt.

When choosing a sweetener, many things need to be considered.
is the goal? For example, are you trying to reduce calories, increase sweetness, reduce sweetness, or replace the sugar in a product? Is labeling, such as “reduced calorie” or “sugar free,” important? Do you want the finished product to have essentially the same taste and appearance as a traditional product? If so, not only taste, but also texture and bulk are especially important. How long a shelf life is required? Some sweeteners may not hold up well in an acidic product over time. Will the product require baking or heating? Some sweeteners may break down at prolonged high temperatures, while others may develop a metallic taste when heated. What other ingredients does the product contain that might interact with the sweetener? Some sweeteners enhance fruit flavors. Is this important to your new product?

It is important to remember that in developing low-calorie products, low-calorie sweeteners cannot be simply substituted for sugar. Products must be reformulated. The various sweeteners interact differently with other food ingredients, so the flavoring acid/sweetness ratio may require modification. And, of course, low-calorie sweeteners do not provide bulk.

Approved Low-Calorie Sweeteners

Four low-calorie sweeteners are currently approved by the Food and Drug Administration for use in the U.S.

• **Acesulfame potassium** (acesulfame K) is approved for use in a wide range of products, including tabletop sweeteners, desserts, puddings, baked goods, candies, and soft drinks. A petition was recently filed with FDA for its use as a general purpose sweetener and flavor enhancer. It dissolves readily in water, even at room temperature, and is very stable, with virtually no change in concentration observed in the pH range common for foods and beverages after several months. Beverages containing acesulfame K can be pasteurized under normal pasteurization conditions without loss of sweetness. Decomposition in baked goods is only found at temperatures well over 200°C. It blends well with other sweeteners and is especially synergistic with aspartame and sodium cyclamate but less so with saccharin. Prior to approval, acesulfame K was the subject of a comprehensive safety evaluation program that confirmed its safety.

• **Aspartame** is approved for general use in the U.S. and therefore may be used
in any product where a standard of identity does not preclude its use. For example, if a standard called for a "nutritive carbohydrate sweetener," aspartame would not be appropriate. However, it could be used in a product whose standard calls for a "nutritive sweetener"—although it technically has 0.4 kcal/g, as used it provides essentially no calories because it is 200 times sweeter than sugar.

Studies have demonstrated that the taste profile of aspartame closely resembles that of sucrose. It enhances various food and beverage flavors, especially fruit flavors. Although aspartame may hydrolyze with excessive heat, it can withstand the heat processing used for dairy products and juices, aseptic processing, and other processes in which high-temperature, short-time and ultra-high-temperatures are used.

Aspartame is slightly soluble in water, sparingly soluble in alcohol, but not soluble in fats or oils. Under dry conditions, it has good stability. In liquids under certain conditions of moisture, temperature, and pH, it may hydrolyze, resulting in loss of sweetness.

No adverse health effects related to aspartame have been demonstrated, but this has not stopped its critics. Inaccurate information about aspartame has been circulating, especially on the Internet, associating aspartame with any number of diseases. This misinformation has prompted a number of responses. FDA has stated that aspartame is one of the most thoroughly tested food additives ever submitted to the agency and "All of the early testing in animals and human subjects conducted to support the safety of aspartame as well as the well-designed and conducted studies subsequently performed to assess whether aspartame might mediate a number of anecdotally reported symptoms have reinforced the appropriateness of FDA's approval and regulation of aspartame as a safe food additive."

Most recently, the French Food Safety Agency conducted an extensive review of aspartame, prompted by negative allegations about it, and determined that there is no scientific data to support these allegations.

• Saccharin is approved in the U.S. as a special dietary sweetener. It is commercially available in three forms: acid saccharin, sodium saccharin, and calcium saccharin. Sodium saccharin is the most commonly used form because of its high solubility and stability. Calcium saccharin, however, might be chosen for a "sodium-free" product. In its bulk form, saccharin and its salts have been shown to be stable for several years. In aqueous solutions, saccharin demonstrates high stability over a wide pH range.

Saccharin has been available for more than 100 years. In 1977, FDA proposed banning it, on the basis of controversial high-dose rat studies in which rats fed the human equivalent of sodium saccharin in hundreds of cans of diet soft drinks each day for a lifetime developed bladder tumors. Congress placed a moratorium on the proposed ban but required saccharin-containing products to bear a warning label indicating that saccharin had been shown to cause tumors in laboratory animals. In 1991, FDA withdrew its proposal to ban. In 2000, the U.S. National Toxicology Program delisted saccharin from its list of potential carcinogens, and, as a result, Congress removed the saccharin warning label requirement.

• Sucralose also has been granted U.S. approval as a general-purpose sweetener. The sweetest of the currently approved sweeteners (600 times sweeter than sucrose), it has a clean, quickly perceptible sweet taste. Its excellent chemical and biological stability, both dry and in aqueous solution, allows for its use essentially anywhere sugar is used, including cooking and baking. The solubility and aqueous stability of the sweetener allow for sucralose to be provided as a liquid concentrate for industrial use. This product provides an extremely stable ingredient system compatible with most food operations. Studies in model food systems, confirmed by actual product use, demonstrate that sucralose can be used in dry food applications, with no expectation of discoloration when food products are handled in normal food distribution systems.

Sucralose is being used in a broad range of products. The actual use level varies with the sweetness level desired and the other ingredients and flavor system used in the specific formulation. It has been thoroughly tested in more than 100 studies over a 20-year period and found to be safe. It passes rapidly through the body virtually unchanged.

Low-Calorie Sweeteners Pending Approval

Three additional low-calorie sweeteners—alitame, cyclamate, and neotame—are pending approval by FDA. Of the three, neotame is expected to be approved first.

• Neotame is a both a low-calorie sweetener and a flavor enhancer. It is structurally similar to aspartame but 30–60 times sweeter—or 7,000–13,000 times sweeter than sucrose. Neotame is stable across a wide range of applications. It is similar in stability to aspartame but has greater stability in baked and dairy products. Neotame's clean, sweet taste is maintained over the range of concentrations required for numerous food and beverage applications. It extends both sweetness and flavor in confectionery applications, such as sugar-free chewing gum, and its onset and linger are similar to those of sucrose in applications such as powdered soft drinks. It is soluble in ethanol, and its solubility increases in both water and ethyl acetate with increasing temperature. It dissolves rapidly in aqueous solutions, since very little is needed as a result of its intense sweetness.

Extensive research has been conducted confirming neotame's safety for human consumption. FDA is evaluating neotame for general use and may approve it as a sweetener and flavor enhancer in the not-too-distant future.

• Alitame is formed from the amino acids L-aspartic acid and D-alanine, with a novel amide moiety (formed from 2,2,4,4-tetramethylthienylamine). This novel amide is responsible for the intense sweetness of alitame, 2,000 times that of sucrose. Alitame's sweetness is described as sucrose-like, without bitterness or metallic notes. It is a crystalline, odorless, nonhygroscopic powder that is very soluble in water at the isoelectric pH. Excellent solubility is seen in other polar solvents, as well. This sweetener is sufficiently stable for use in hard and soft candies, heat-pasteurized foods, and neutral-pH foods processed at high temperatures, such as sweet baked goods.

Alitame is compatible with a wide variety of freshly prepared foods. It can undergo chemical reactions with certain food components. For example, high levels of reducing sugars, such as glucose and lactose, may react with alitame in heated liquid and semiliquid systems, such as baked goods, to form Maillard reaction products. Similar reactions may be observed when high levels of aldehydes are present. Prolonged storage in liquid beverages may result in off-flavors in the presence of hydrogen peroxide, sodium bisulfite, ascorbic acid, and some type of caramel color at pH values below 4.0. Research is underway to resolve these issues.

• Cyclamate is available for use in more than 50 countries but not currently in the U.S. It is almost always used in combina-
tion with other sweeteners. It has a favorable flavor profile and is better able to mask bitterness than sugar. It is compatible with most food ingredients, natural and artificial flavoring agents (enhancing fruit flavors), and chemical preservatives. It is extremely stable at both high and low temperatures, over a wide pH range, as well as in the presence of light, oxygen, and other food ingredients.

Cyclamate is particularly well suited for fruit products because it enhances fruit flavors and even at low concentrations can mask the tartness of some citrus fruits. Canned fruit is one product in which it has been used as the sole sweetener. Cyclamate solutions used for such products have a lower specific gravity and osmotic pressure than sucrose syrups and therefore do not pull water out of the fruit. It is suitable for tabletop sweeteners and beverages. Before it was banned in the U.S., cyclamate was responsible for the popularity of several brands of diet soft drink.

Cyclamate can also be used in gelatins, jams, jellies, and low-calorie salad dressings. With the proper combination of other ingredients to provide bulk and texture, it can be used in baked goods. It has also been used in cured meats. It has a higher melting point than sugar and does not caramelize when fried. For example, cyclamate-cured ham and bacon have improved flavor and color and do not scorch or stick to the frying pan.

• **Stevioside** is mentioned here because of the considerable attention it receives from those promoting “natural.” Stevioside may be used as a dietary supplement in the U.S., but it is not approved as a sweetener and no reference to sweetness should be made. Although it is approved in Japan, South Korea, Brazil, Argentina, and Paraguay, both the Food and Agriculture Organization/World Health Organization’s Joint Expert Committee on Food Additives (JECFA) and the European Union’s Scientific Committee for Food have reviewed stevioside and determined that it is not acceptable as a sweetener on the basis of presently available data, which are considered insufficient.

**Polysols**

As noted above, the low-calorie sweeteners lack the bulk needed for many products in which they are used. Polysols are often used in combination with the low-calorie sweeteners to provide bulk and improve texture and mouthfeel. There are currently eight polysols available for use in the U.S.

JECFA has evaluated the available data—chemical, biochemical, toxicological, and other—on polysols and determined that the total daily intake of each polysol, arising from its use at the levels necessary to achieve the desired effect, does not represent a hazard to health. For that reason and for reasons stated in the individual evaluations, the committee deemed it not necessary to assign an numerical value for Acceptable Daily Intake (ADI) but instead assigned the most favorable term, “not specified.”

Sugar-free products sweetened with polysols or sugar replacements are reduced in calories but are not calorie free. Based on an evaluation of a large number of studies by the Federation of American Societies for Experimental Biology’s Life Sciences Research Office, FDA allows the use of the following caloric values: 0.2 kcal/g for erythritol, 1.6 for mannitol, 2.0 for isomalt and lactitol, 2.1 for maltitol, 2.4 for xylitol, 2.6 for sorbitol, and 3.0 for hydrogenated starch hydrolysates—compared to 4 kcal/g for sucrose.

These reduced values for polysols are important to the manufacturers of polyol-containing products. Under current regulations, reduced calorie foods must have a 25% caloric reduction from their full-calorie counterparts. In many polyol-containing products, the polyol or a combination of polyols constitutes the principal ingredient. Therefore, with a caloric value of 3 kcal/g or less, the product may be able to make a reduced-calorie claim. For example, products sweetened exclusively with polyols or a combination of polyols and low-calorie sweeteners may bear a “sugar-free” claim. However, unless the product is reduced-calorie (i.e., has at least 25% fewer calories than its traditional full-calorie counterpart), the label must also state that the food is not a reduced-calorie food.

FDA also has authorized the use of the “does not promote tooth decay” health claim for sugar-free foods products sweetened with polyols. And the American Dental Association has approved a position statement acknowledging the “Role of Sugar-Free Foods and Medications in Maintaining Good Oral Health.” ADA recognizes that “it is neither advisable nor appropriate to eliminate from the American diet sugar-containing foods that provide necessary energy value for optimal nutrition.” The association recommends, however, “that major efforts be made to promote the use of sugar-free foods or chewing substances in place of sugar-containing foods that involve a frequent intake or repeated oral use. . . . Use of these sugar-free products will contribute to improved oral health.”

• **Erythritol** is the newest polyol. It is an odorless white crystalline powder with a clean sweet taste. It is approximately 70% as sweet as sugar but provides only 0.2 kcal/g. It is nonhygroscopic and moderately soluble in water. It is stable at high temperatures and over a wide pH range and has a mild cooling effect in the mouth. It is suitable for use in a number of food products, including chewing gum, candies, chocolate, lozenges, fondant, fudge, bakery products, beverages, and tabletop sweeteners.

• **Hydrogenated starch hydrolysates**, including maltitol syrups, sorbitol syrups, and hydrogenated glucose syrups, are a family of products found in a wide variety of foods. The term hydrogenated starch hydrolysate can correctly be applied to any polyol produced by the hydrolysis of the saccharide products of starch hydrolysis. In practice, however, certain polyols such as sorbitol, mannitol, and maltitol are referred to by their common chemical names. The term hydrogenated starch hydrolysate is more commonly used to describe the broad group of polyols that contain substantial quantities of hydrogenated oligo- and polysaccharides in addition to any monomeric polyols (e.g., sorbitol or mannitol) or dimeric polyols (e.g., maltitol). The broad term does not differentiate polyols with different sweetness levels, and it does not identify the principal polyol in the hydrogenated starch hydrolysate. Common names have, therefore, been developed for major subgroups. These common names are usually based on the most common polyol in the hydrogenated starch hydrolysate. For example, polyols that are 50% or more sorbitol are known as sorbitol syrups, and those that are 50% or more maltitol are called maltitol syrups. Polyols that do not have a majority component are referred to by the general term hydrogenated starch hydrolysate.

Hydrogenated starch hydrolysates are 40-90% as sweet as sugar and serve a number of functional roles, including use as bulk sweeteners, viscosity and bodying agents, humectants, crystallization modifiers, cryoprotectants, and rehydration aids. They can also carry flavors, colors, and enzymes. Since they are excellent humectants which do not crystallize, they can be used in the production of sugar-free confections with the same cooking and handling systems used to produce sugar candies. Their ex-
cellent humectancy also makes them suitable for baked goods. Also, they do not have reducing groups, thereby minimizing Maillard browning reactions. They are also used to replace sugar in a variety of frozen desserts, since they do not form crystals.

• Isomalt has a sweet taste similar to sucrose and reinforces flavor transfer in foods. It is 0.45–0.6 times as sweet as sucrose and, unlike most polyols, does not produce a cooling effect. Isomalt can replace sugar in many foods, using existing processing equipment without major changes. Hard-boiled candies made with it, for example, can be stamped, filled, pulled, combed, and molded and have very good shelf life. Minor changes in the production of these products are required, since isomalt has lower solubility, a higher melting point, lower viscosity of the melt, and a higher specific heat capacity than sucrose or corn syrup.

Isomalt can also be used in pan-coated products, chewing gum, chocolate, low-boiled candies, ice cream, jams and preserves, fillings, fondant, and baked goods. “Light” baked goods with isomalt require only minimal formulation modifications. Isomalt’s low solubility, low hygroscopicity, and browning reaction should be considered. The final baked product containing isomalt has a sugar-like taste with a long shelf life. Isomalt cookies absorb less water than sugar formulations, so are crisper.

• Lactitol has a clean taste about 0.4 times as sweet as sucrose, without an aftertaste. A low-calorie sweetener also may be needed in some applications to provide the desired sweetness. Lactitol is nonhygroscopic, making it suitable for all applications in which water absorption is a critical issue, such as bakery products, tablets, and canned confections. Since its molecular weight is similar to that of sucrose, its influence on water activity is also similar to that of sucrose (on a dry-weight basis). It is stable in acidic and alkaline conditions and under the high temperatures of food processing. Lactitol is suitable for a wide range of products, from baked goods to frozen dairy desserts.

The prebiotic effects of lactitol have been studied. Lactitol reaches the colon untouched and can be used as an energy source by intestinal microflora. In-vitro studies show that lactitol stimulates the growth of Lactobacillus and Bifidobacteria.

• Maltitol has many attributes that allow its use in a wide variety of food applications. It is a white crystalline powder with a sweetness profile similar to that of sugar, is substantially nonhygroscopic, and is thermostable. It exhibits a negligible cooling effect and can be used to replace fat as well as sugar, since it provides a creamy texture to brownies, cakes, and cookies. This attribute also facilitates its use in sucrose-free chocolate. Maltitol’s anhydrous crystalline form, low hygroscopicity, high melting point, and stability allow it to replace sucrose in high-quality chocolate coatings, confectionery, bakery chocolate, and ice cream. It is also suitable for granola bars, jams with no added sugar, pie fillings, salad dressings, and spreads. Although maltitol works well with other sweeteners, the use of a low-calorie sweetener is not required because maltitol is nearly as sweet as sucrose.

• Mannitol has long been used in food and pharmaceutical products. It is nonhygroscopic, so it is often used as a dusting powder for chewing gum to prevent the gum from sticking to the manufacturing equipment and wrappers. It also is used a part of the plasticizer system to help maintain the soft texture of the gum. Because of its high melting point (165–169°C), it is used in chocolate-flavored coating agents for ice cream and confections. It has a pleasant taste and does not discolor at high temperatures. FDA requires the statement “Excess consumption may have a laxative effect” on the label of a food if the daily consumption of mannitol in the food might exceed 20 g.

Mannitol is used in tableting applications as a diluent or filler. Because of its chemical inertness, it is one of the most stable tablet diluents available and is most often used in chewable tablets because of its pleasant taste and mouthfeel, as well as its ability to mask the bitter taste of vitamins and minerals, herbs, or active pharmaceutical ingredients.

• Sorbitol has been used in processed foods for half a century as a sweetener, humectant, and texturizing agent. It has a smooth mouthfeel, is 0.6 times as sweet as sucrose, and has a cool, pleasant taste. Its moisture-stabilizing and textural properties are important to the production of confectionery, baked goods, and chocolate, where products tend to become dry or harden. It is very stable and chemically unreactive. It can withstand high temperatures and does not participate in Maillard reactions. It combines well with other food ingredients, including sugars, gelling agents, proteins, and vegetable fats. In addition to the products mentioned above, it functions well in chewing gums, frozen desserts, icings, and fillings.

Sorbitol is affirmed by FDA as Generally Recognized As Safe (GRAS). However, FDA requires that the statement “Excess consumption may have a laxative effect” on the label of a food if the daily consumption of sorbitol in the food might exceed 50 g. Although laxative statements are not required in the U.S. on products containing polyols other than mannitol and sorbitol, polyol manufacturers may recommend that their customers place a similar statement on products the daily consumption of which might be expected to exceed a specified limit.

• Xylitol is used mainly in noncariogenic confections such as chewing gum, candies, chocolates, and gum drops. In both clinical and field studies, xylitol use between meals is associated with significantly reduced formation of new caries, even when participants were already practicing good oral hygiene. It is approved as a direct food additive for foods for special dietary purposes in the U.S.

Xylitol is as sweet as sucrose. Crystalline xylitol provides a significant cooling effect. The cooling effect enhances the perception of mint flavor but is most notable in sugar-free chewing gum, compressed candies, and chewable vitamins. The cooling effect is not perceived in jellies or boiled, transparent candies. Xylitol’s solubility is similar to that of sucrose. It is chemically inert and does not participate in Maillard reactions.

Other New Sweeteners

There are two new sweeteners also of interest—tagatose and trehalose.

• Tagatose occurs naturally in dairy products, but the commercial product is made via a patented process. It has the bulk of sugar, is almost as sweet, but provides only 1.5 kcal/g. It has the potential for use in many products where sucrose is currently used, such as confections, ice cream, soft drinks, cereals, and meal replacements. It is synergistic with other sweeteners and can be used with low-calorie sweeteners to improve texture and mouthfeel. Its solubility in water is similar to that of sucrose. It is nonhygroscopic, with lower water activity than sucrose. Tagatose-containing products “brown” more readily than sucrose-containing baked goods. It has also been shown to have prebiotic properties.

Under FDA’s GRAS notification system, manufacturers may make a self-determination that a substance is Generally Recogni-
Neotame: The Next-Generation Sweetener

A new sweetener derived from aspartame is thousands of times sweeter than sugar and does not have the undesirable taste characteristics common to some high-intensity sweeteners.

Neotame, a new high-intensity sweetener and flavor enhancer, is expected to receive Food and Drug Administration approval for use in foods and beverages in the United States soon. Since it will then be the newest approved sweetener in the U.S., it is appropriate to review its development, characteristics, and potential uses.

Overview

Neotame is a derivative of the dipeptide composed of the amino acids aspartic acid and phenylalanine. It is 7,000-13,000 times as sweet as sugar and 30-60 times as sweet as aspartame. It is manufactured by The NutraSweet Co., Mt. Prospect, Ill., the company that developed the noncaloric sweetener aspartame.

It provides zero calories and has a clean, sweet, sugar-like taste with no undesirable taste characteristics. It is functional in a wide array of beverages and foods and can be used alone or blended with other high-intensity or carbohydrate sweeteners. It is stable under dry conditions, and has comparable stability to aspartame in aqueous food systems and more stable in neutral pH conditions (e.g., baking and yogurt).

The results of numerous safety studies confirm that it is safe for use by the general population, including children, pregnant women, and people with diabetes. In addition, since the product is not metabolized to phenylalanine, no special labeling for individuals with phenylketonuria (PKU) is required. Neotame has been approved for general use as a sweetener and flavor enhancer in Australia and New Zealand and is being reviewed in the U.S. and other countries.

Discovery and Manufacture

Neotame was the result of a long-term research program by The NutraSweet Co. to discover new high-intensity sweeteners with desirable taste characteristics. Working with The NutraSweet Co., French scientists Claude Nofre and Jean-Marie Tinti prepared a series of compounds by substituting the terminal nitrogen of aspartame with a number of hydrophobic groups and determined their sweetness compared to a 2% solution of sucrose. Aspartame substituted with a 3,3-dimethylbutyl group was the sweetest of the compounds tested and was selected as development product and called neotame (Nofre and Tinti, 1996b, 2000). This compound has the chemical structure as shown in Fig. 1.

As shown in Fig. 2, neotame can be made in one step by the reaction of aspartame with 3,3-dimethylbutyraldehyde in methanol, using hydrogen and a catalyst (palladium or platinum) under mild conditions (Nofre and Tinti, 1996a; Prakash, 1998). Other possible methods of preparation are from aspartame precursors via the reductive alkylation with 3,3-dimethylbutyraldehyde; peptide coupling of the L-aspartic acid derivatives and L-phenylalanine methyl ester; aminolysis of substituted oxazolidinone derivatives (Prakash, 2001; Prakash and Chapeau, 2000; Prakash et al., 2001b).
Characteristics

Neotame's physical, chemical, and sensory characteristics make it attractive for use as a sweetener in foods and beverages.

**Chemical Characteristics.** Neotame is \( \text{N}-\text{N-(3,3-dimethylbutyl)-L-}\alpha\text{-aspartyl}-\text{L-phenylalanine 1-methyl ester (CAS registry No. 165450-17-9, proposed INS No. 961). It is a derivative of a dipeptide composed of the amino acids aspartic acid and phenylalanine. It contains both a carboxylic acid and a secondary amino group, with } pK_a \text{ values of 3.03 and 8.08, respectively. It is capable of forming both acidic and basic salts, as well as complexes with various metals, thus affording unique delivery forms having improved solubility and other characteristics.}

The two amino acids in neotame, aspartic acid and phenylalanine, are in the natural L-configuration. The other three possible isomers, L,D-, D,D-, and D,L-, lack the sweet taste of neotame (Prakash et al., 1999).

**Physical Characteristics.** Neotame is a fairly low-melting hydrate (80.9–83.4°C). It is a white to off-white crystalline powder with 4.5% water of hydration, the empirical formula \( \text{C}_{20}\text{H}_{30}\text{N}_2\text{O}_5\cdot\text{H}_2\text{O} \), and a molecular weight of 396.48.

Its solubility in water is similar to that of aspartame (12.6 g/L vs 10 g/L at 25°C), but it is more readily soluble than aspartame in some solvents, such as ethanol, typically used in food systems and pharmaceuticals. Its solubility in water and ethyl acetate increases with increasing temperature. Using neotame in a salt form (e.g., as a phosphate salt) significantly increases the rate of dissolution.

**Stability.** The stability of neotame is dependent on pH, moisture, and temperature. As a dry powder, it is stable for at least five years under proper storage conditions. In aqueous systems, pH stability follows a bell-shaped curve at a given temperature. The optimum pH for maximum stability is about 4.5. As expected, stability decreases with increasing temperature. Stability can be enhanced by the addition of divalent or trivalent cations in edible compounds (Schroeder and Wang, 2001b).

In aqueous systems (pH 2–8), the major decomposition pathway of neotame is through the hydrolysis of the methyl ester to form de-esterified or de-methylated neotame—\( \text{N}-\text{N-(3,3-dimethylbutyl)-L-}\alpha\text{-aspartyl}-\text{L-phenylalanine (Fig. 3)—which is also the major metabolite of neotame in humans. De-esterified neotame is not sweet.}

Under conditions of use, neotame, unlike aspartame, does not degrade to phenylalanine. Also unlike aspartame, neotame does not form a diketopiperazine (DKP) derivative. Neotame is compatible with reducing sugars and aldehyde or ketone-based flavoring agents.

**Sweetness.** Sucrose is the sweetness standard against which other compounds are compared. A compound with a “sucrose equivalence” of x% SE is equivalent in sweetness to an x% solution of sucrose in water. Neotame is approximately 8,000 times as sweet as sucrose and more potent than the high-intensity sweeteners currently marketed in the U.S.—aspartame and acesulfame K (200 times as sweet as sucrose), saccharin (300 times), and sucralose (600 times). It is a derivative of aspartame and is 30–60 times sweeter than aspartame. Its actual sweetness potency is dependent on the concentration required in various food or beverage products.

Because of its remarkable sweetness potency, neotame can be used in food and beverage products at considerably lower concentrations than other high-intensity sweeteners. In fact, consumer exposure to neotame will be much lower than exposure to flavoring ingredients such as vanillin, cinnamon, and menthol commonly used in foods and beverages.

The concentration–response curve for neotame (Fig. 4) was established using a trained sensory panel to evaluate the sweet-
ness intensity of five solutions of neotame at increasing concentrations. Based on these data, neotame can reach an extrapolated maximum sweetness intensity (plateau) of 15.1% SE in water. Sweeteners such as aspartame, acesulfame K, sodium cyclamate, and sodium saccharin attain their maximum sweetness intensity in water at approximately 16.0, 11.6, 11.3, and 9.0% SE, respectively. In a cola formulation, neotame reaches a maximum sweetness intensity of 13.4% SE (DuBois et al., 1991).

• **Taste Profile.** A trained descriptive panel evaluated neotame and sucrose at comparable sweetness levels in water. Neotame's taste profile is very similar to that of sucrose, with the predominant sensory characteristic being a very clean, sweet taste. The sweetness increases as the concentration in water increases, but other taste attributes such as bitterness, sourness, and metallic taste are insignificant (Fig. 5). In a similar study with neotame in a cola drink, increasing the sweetener concentration from 9 to 46 ppm improved the desirable flavor attributes (cola flavor, sweet taste, and mouthfeel) but did not increase the undesirable notes (Fig. 6).

• **Sweetness Temporal Profile.** The temporal profile of sweeteners demonstrates the changes in the perception of sweetness over time. This property is a key to the functionality of a sweetener and is complementary to its taste profile. Every sweetener exhibits a characteristic onset or response time and an extinction time. Most high-intensity sweeteners, in contrast to sugar, display a prolonged extinction time referred to as “linger.”

As shown in Fig. 7, the sweetness temporal profile of neotame in water is close to that of aspartame, with a slightly slower onset and slightly longer linger. A longer sweetness linger can be beneficial in some products, such as chewing gum, where prolonged sweetness is a desirable quality.

The sweetness temporal profile of neotame may also be modified by the addition of hydrophobic organic acids, such as cinnamic acid, and certain amino acids, such as serine and tyrosine (Bishay et al., 2000b; Gerlat et al., 2000; Prakash et al., 2001a). Taste modifiers may be used in concentrations necessary to achieve the desired taste profile of a product for a desired application.

• **Synergy.** Blending of sweeteners is well known to improve taste characteristics and stability and provide sweetness synergy (Lavie and Hill, 1972; Schifman et al., 1995; Scott, 1971; Verdi and Hood, 1993; Walters, 1993). A blend of neotame and saccharin provides 14–24% greater sweetness than would be predicted by adding together the sweetness intensities of the individual sweeteners (Pajor and Gibes, 2000). Such synergistic blends offer cost savings by decreasing the total amount of sweetener needed. Neotame can be blended with nutritive sweeteners as well as other high-intensity sweeteners such as aspartame, acesulfame salts, cyclamate, sucralose, saccharin, and others (Nofre and Tinti, 1996b). Furthermore, the clean sweetness of neotame permits its substitution for substantial amounts of carbohydrate sweeteners without altering the flavor of the product.

Because time–intensity profiles of the sweeteners acting synergistically are different from those of the individual sweeteners and may also be different from that of sucrose, blends can be selected that combine or emphasize the properties of the different sweeteners. The sweetness of acesulfame K is generally perceived fairly quickly. It may, therefore, provide some impact sweetness, but it often fades fairly quickly. Therefore, acesulfame combines particularly well with sweeteners having a more lasting sweetness, such as aspartame or neotame.

• **Sugar Substitution.** Neotame's clean sweet taste allows the food technologist to substitute a portion of a carbohydrate sweetener with neotame while maintaining a taste that is indistinguishable from the 100% carbohydrate product. For example, studies have shown that 20% of the carbohydrate sweetener can be replaced with 2.1 ppm of neotame in a carbonated cola soft drink, and the taste is indistinguishable from the 100% carbohydrate–sweetened cola beverage (Fig. 8). Neotame's potency may offer an economic benefit and, because it has no calories, a positive caloric benefit.

• **Flavor Modification and Enhancement.** Neotame can also be used to modify or enhance a product's flavor—the
Food Applications

Flavors, and mixtures thereof (Gerlat et al., 2000). It modifies or enhances the attributes of many flavoring chemicals or eliminates “beany” flavor notes in soy products. And in salt substitutes, thereby providing a cleaner salty taste. It retains and plant extracts, can be modified or masked. Neotame also reduces the bitter taste of potassium chloride in salt substitutes, thereby providing a cleaner salty taste. It reduces or eliminates “beany” flavor notes in soy products. And it modifies or enhances the attributes of many flavoring chemicals, including essential oils, oleoresins, plant extracts, reaction flavors, and mixtures thereof (Gerlat et al., 2000).

Food Applications

Historically, the stability and functionality of a new sweetener or an ingredient was determined for each food product before the sweetener was approved. This process generated redundant data. This redundancy could be avoided if products with similar ingredients and processing conditions could be reduced to representative test products for evaluation.

The functionality of neotame was demonstrated with a three-dimensional food matrix model representing the intended conditions of use in foods (Pariza et al., 1998). Based on experience with aspartame and the structural similarities of neotame and aspartame, product moisture, process temperature, and product pH were considered to be the key factors responsible for neotame stability and were selected to represent the three dimensions of the matrix.

Test products were prepared according to standard formulas, then packaged appropriately, stored at temperature conditions of up to 25°C and 60% relative humidity, and evaluated for stability at appropriate intervals. Neotame concentrations were determined using validated high-performance liquid chromatography methods.

Functionality (sweetness) of the test products was determined using panels consisting of 35–50 persons. Samples were appropriately prepared, served, and evaluated on a scale ranging from 5 (“much too sweet”) to 1 (“not at all sweet”). The samples were considered functional if no more than 75% of the panelists rated the sweetness as 2 (“not quite sweet enough”) and 1.

Delivery Forms and Benefits

Neotame can be prepared in a wide variety of forms, including agglomerated (Fotos et al., 2001), granulated (Dron, 2001), extruded and spheronized (Dron et al., 2000), encapsulated (Ponakala et al., 1999), co-crystallized with sugar (Fotos et al., 2001), acid salts (Prakash and Wachholder, 2001a), basic salts (Prakash and Wachholder, 2001b), sweetener salts (Prakash and Guo, 2000b), amorphous (Schroeder and Bang, 2001a), metal complexes (Prakash and Guo, 2000a), cyclodextrin complexes (Bishay et al., 2000a), and liquid (Schroeder et al., 2000). In certain uses, these delivery forms offer various advantages over neotame powder, such as ease of handling, non-dustiness, and improved solubility characteristics, bringing greater flexibility to product developers.

Neotame provides several benefits as a sweetener and/or flavor enhancer in food and beverage systems. It is noncaloric; it requires no PKU labeling; it is not likely to react with aldehydes and consequently may be compatible with flavors containing aldehydes. Because of its high potency, the quantity required to sweeten a product is about 1/30 to 1/60 of the amount of aspartame required. It enhances the flavor of some ingredients, such as mint and suppresses the beany notes of Cola-Flavored Carbonated Soft Drink. Neotame remained functional for at least 16 weeks, consistent with currently marketed low-calorie carbonated soft drinks (Gerlat et al., 1999).


Powdered Soft Drink. At each evaluation, the sweetness of the reconstituted drink received a rating of “just about right,” indicating that the product was stable and functional as a sweetener during 52 weeks of storage.

Tabletop Products. Neotame was considered stable and functional in tabletop products for at least 156 weeks of storage (FAP, 1998; Towb et al., 2002).

Chewing Gum. Encapsulation improved neotame stability. Double coating with modified starch and hydroxypropyl methylcellulose protected it from degradation during storage for 52 weeks (Rofer, 2002).

Dairy Products/Strawberry Yogurt. At the end of a 6-week period, the typical shelf life of these products, about 98% of the initial neotame remained. Sensory results showed that neotame had excellent functionality in yogurt (FAP, 1998; Gaughan et al., 1999).

Yellow Cake. Neotame was functional, with 82% of the amount added to the batter remaining after baking at 350°F. After storage at 25°C and 60% relative humidity for 5 days—which is longer than cakes baked from commercial mixes are held for optimum freshness—there was only a 4% loss of neotame. The combined losses of about 20% did not affect sweetener functionality (Chinn et al., 1999; FAP, 1998).

Other Products. Functionality has also been demonstrated in cereals and cereal-based foods (Ponakala and Corliss, 2000), nutraceuticals (Ponakala et al., 2000a), pharmaceuticals (Ponakala, 2001), edible gels (Ponakala et al., 2000b), and confectionery products (Jarrett, 2001).

Table 1 presents some typical use levels of neotame in various foods and beverages. Since neotame is extremely sweet, the use levels are expressed as parts per million rather than percentages. The ranges provided are for neotame used either as a single sweetener or as a component in a sweetener blend.

<table>
<thead>
<tr>
<th>Delivery Form</th>
<th>Use Level</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Powdered Soft Drink</td>
<td>100% HFCS</td>
<td>Yields best results.</td>
</tr>
<tr>
<td>Cola-Flavored Carbonated Soft Drink</td>
<td>20%/80% blend</td>
<td>Good flavor enhancement.</td>
</tr>
<tr>
<td>Hot-Pack Lemon Tea</td>
<td>100% HFCS</td>
<td>Suitable for shelf-stable products.</td>
</tr>
<tr>
<td>Chewing Gum</td>
<td>20%/80% blend</td>
<td>Provides a pleasant texture.</td>
</tr>
<tr>
<td>Yellow Cake</td>
<td>100% HFCS</td>
<td>Improves shelf life.</td>
</tr>
<tr>
<td>Dairy Products/Strawberry Yogurt</td>
<td>20%/80% blend</td>
<td>Maintains flavor consistency.</td>
</tr>
<tr>
<td>Other Products</td>
<td>100% HFCS</td>
<td>Extends shelf life in various forms.</td>
</tr>
</tbody>
</table>

Fig. 8— Descriptive test results of carbonated cola beverages sweetened with 100% high-fructose corn syrup and a 20%/80% blend of HFCS and neotame.
soy, in various food and beverage systems. It masks bitterness. It can complement the flavor of root beer beverages. In fruit-based juices, because of the increased mouthfeel it contributes, juice solids can be reduced. It has a sparing effect on the flavoring agent vanillin in puddings; on cocoa, dairy component, and vanillin in chocolate and cocoa-based products; on dairy and fruit components, such as citric acid, in yogurt; and on tomato flavor in barbeque sauces.

Safety and Regulatory Status

The results of extensive research done in animals and humans using amounts of neotame that far exceed expected consumption levels clearly confirm its safety for the general population, including children, pregnant women, and people with diabetes. Neotame is not mutagenic, teratogenic, or carcinogenic and has no effect on reproduction. In addition, no special labeling for phenylketonuric individuals is required. The major route of metabolism of neotame is de-esterification. Both neotame and de-esterified neotame have short plasma half-lives, with rapid and complete elimination (FAP, 1998, 1999).

The Food and Drug Administration is currently reviewing a food additive petition for approval of neotame for general use in food as a sweetener and flavor enhancer, and petitions for regulatory approval have been filed in a number of foreign countries. Australia and New Zealand have already approved use of neotame as a sweetener and flavor enhancer.

Neotame’s unique properties will provide the food technologist with another tool to produce innovative new foods and beverages to meet consumers’ demands for great-tasting foods without all the calories of sugar.

Table 1—Typical neotame concentrations in various products when used as a sweetener

<table>
<thead>
<tr>
<th>Product</th>
<th>Typical concentration (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbonated soft drinks</td>
<td>2–50</td>
</tr>
<tr>
<td>Cola</td>
<td>17</td>
</tr>
<tr>
<td>Lemon-lime</td>
<td>14</td>
</tr>
<tr>
<td>Root beer</td>
<td>20</td>
</tr>
<tr>
<td>Flavored water</td>
<td>15</td>
</tr>
<tr>
<td>Still beverages</td>
<td>2–20</td>
</tr>
<tr>
<td>Red punch</td>
<td>15</td>
</tr>
<tr>
<td>Lemonade</td>
<td>16</td>
</tr>
<tr>
<td>Ready-to-drink tea</td>
<td>8</td>
</tr>
<tr>
<td>Powdered soft drink, as is</td>
<td>200–2,000</td>
</tr>
<tr>
<td>Lemon-flavored</td>
<td>16</td>
</tr>
<tr>
<td>Tabletop sweetener, as is</td>
<td>800–4,000</td>
</tr>
<tr>
<td>Lemon tea</td>
<td>12</td>
</tr>
<tr>
<td>Bakery products</td>
<td>6–130</td>
</tr>
<tr>
<td>Cookie</td>
<td>25</td>
</tr>
<tr>
<td>Yellow cake</td>
<td>35</td>
</tr>
<tr>
<td>Chocolate cake</td>
<td>125</td>
</tr>
<tr>
<td>Fillings</td>
<td>25</td>
</tr>
<tr>
<td>Frosting</td>
<td>25</td>
</tr>
<tr>
<td>Dairy products</td>
<td>5–50</td>
</tr>
<tr>
<td>Yogurt</td>
<td>15</td>
</tr>
<tr>
<td>Ice cream</td>
<td>15</td>
</tr>
<tr>
<td>Other frozen desserts</td>
<td>30</td>
</tr>
<tr>
<td>Chewing gum</td>
<td>10–1,600</td>
</tr>
<tr>
<td>Confections</td>
<td>1–200</td>
</tr>
<tr>
<td>Hard candy</td>
<td>5–75</td>
</tr>
<tr>
<td>Cereals</td>
<td>10–500</td>
</tr>
<tr>
<td>Extruded</td>
<td>23</td>
</tr>
<tr>
<td>Frosting</td>
<td>20</td>
</tr>
<tr>
<td>Edible gels</td>
<td>10–1,000</td>
</tr>
<tr>
<td>Nutraceuticals</td>
<td>15–250</td>
</tr>
<tr>
<td>Pharmaceuticals</td>
<td>1–1,000</td>
</tr>
<tr>
<td>Liquid sweetener</td>
<td>10–10,000</td>
</tr>
<tr>
<td>Sweetener tablets</td>
<td>50–12,000</td>
</tr>
</tbody>
</table>

REFERENCES


sweeteners have a great impact on the acceptance of beverages, affecting not only the taste but also their texture. Beverage manufacturers have been using sweetener blends instead of single sweeteners in reduced-calorie beverages for some time now, with many successful products well established in the marketplace. For products that include high-intensity sweeteners, beverage manufacturers tend to use the same sweetener blend and ratio for their full spectrum of flavors in an attempt to save development time. However, by creating new blends of sweeteners or modifying the proportions of current blends, manufacturers can optimize the sweetening systems for specific types and flavors of beverages. Here’s how we approached the development of optimal sweetener blends for various types and flavors of beverages.

**Cola Beverages**

We tested a variety of commercially available sweeteners, both caloric and noncaloric, using a commercially available cola flavoring. A combination of phosphoric and citric acids, commonly used for diet and light colas, was used as the acidulant system. The test beverages were carbonated with 7 g/L. Five high-intensity sweeteners—acesulfame K, aspartame, sodium saccharin, cyclamate, and sucralose—alone and in various combinations (Table 1) were tested, with sucrose as the standard. All sweetening systems were adjusted to a 10% sucrose equivalence, based on sensory assessment; i.e., enough of a sweetener was used to be equivalent in sweetness to a 10% solution of sucrose. Blends were then formulated on the basis of the sweetness contribution of each sweetener. Thus, in a 25/75 blend of two sweeteners, 25% of the sweetness comes from the first sweetener, and 75% from the second. The actual usage volume was adjusted to account for synergy between the sweeteners.
An independent panel of experts trained to evaluate sweet products held a group discussion to determine a list of attributes to be used in a subsequent Quantitative Descriptive Analysis (QDA). Fig. 1 shows these attributes for a sucrose-sweetened sample.

For the QDA, 13 trained panelists conducted a blind tasting of randomized and coded samples and rated them individually on a scale of 0–100. Attribute scores were recorded directly by the panelists via a computerized data input system, and the data were analyzed by two-way Analysis of Variance (ANOVA) and Principal Component Analysis (PCA).

Cola flavors are exceedingly complex systems. Many different flavor components, especially various herbal and citrus notes, are hidden beneath the general taste impression of cola. The character of a particular cola drink results from the dominance of one or more of these top notes.

The results showed not only that the various sweetening systems influence the expression of the overall cola flavor ("total cola," "cola aftertaste") but also that the majority of the systems also emphasize one of the two top notes "spicy" and "lemon-lime" in a specific way. Therefore if a switch is made from a sweetening system that emphasizes the attribute "spicy" to a blend that pushes citrus notes to the forefront, the overall cola character of the beverage will be changed accordingly.

Table 2 shows the expression of the flavor attributes "total cola," "spicy," and "lemon-lime" for a few selected blends. Sucrose strongly emphasizes the citrus notes in a regular cola, while the herbal notes are greatly underrepresented. This leads to a moderate impression of total cola flavor ("total cola"). It is notable that for diet and light colas, particularly good results for "total cola" appeared when "spicy" and "lemon-lime" were evaluated as being in balance (30/70 acesulfame K/sucrose, 30/70 acesulfame K/aspartame, or aspartame) or when "spicy" was more dominant than "lemon-lime" (35/35/30 acesulfame K/aspartame/cyclamate, or 20/80 acesulfame K/sucralose). In contrast, dominance of "lemon-lime" over "spicy," as in the case of 70/30 aspartame/saccharin, resulted in a low rating for "total cola."

This influence of the sweetening system on the top notes was also reflected in the PCA results (not shown). Sucrose set itself apart through a strong expression of "overall sweetness quality" and the absence of artificial notes. The systems 30/70 acesulfame K/sucrose, 30/70 acesulfame K/aspartame, 35/35/30 acesulfame K/aspartame/cyclamate, and aspartame emphasized the flavor attributes "total cola," "spicy," and "total cola aftertaste." On the other hand, 70/30 aspartame/saccharin emphasized more the "lemon-lime" notes of the cola, but also showed significant sidetaste and aftertaste attributes such as "bitter" and "metallic." The 30/70 acesulfame K/aspartame blend provided a more balanced flavor and less sidetaste than the 30/70 aspartame/saccharin blend.

Blends with acesulfame K, such as 20/80 acesulfame K/sucralose, reduced the "artificial sweet" attribute of sucralose used alone and increased the "overall sweetness quality." In addition, acesulfame K reduced the long "sweetness build" and pronounced "sweet aftertaste" of sucralose to result in a more sucrose-like sweetness.

The lack of mouthfeel in low-calorie soft drinks is generally regarded as a negative. In our study on the cola beverage, the sucrose standard surprisingly failed to receive the best results for "thickness," and no significant differences were observed between the sucrose standard and any of the sweetening systems studied. It may be that carbonation plays such a great role in mouthfeel that the influence of the sweetening system is secondary. For a more precise analysis, it would be necessary to conduct a detailed sensory analysis of mouth-
feel. Nonetheless, the results indicate that mouthfeel, especially in carbonated low-calorie drinks, need not be viewed as critically as previously assumed.

Fruit-Flavored Still Beverages

We studied three commonly used flavorings with different characteristics—orange, peach, and strawberry—in a model noncarbonated beverage (citrate buffer, pH 3.2). As in the cola study, different combinations of sweeteners were tested at a sucrose equivalency of 10%.

A panel of testers specially trained in the evaluation of sweet products determined the attributes for the QDA. Table 3 shows the attributes for the peach flavoring. The results of the QDA and PCA showed that whereas the single sweeteners aspartame and sucralose differed significantly from sucrose in their sweetness profile and left a lingering sweet aftertaste, blending them with acesulfame K led to a noticeably more sucrose-like sweetness profile in all cases, an example of synergy.

Sucrose was characterized by a balanced profile with fast sweetness onset without a pronounced sweet aftertaste. It was also associated with positive taste attributes like fruitiness (“total peach,” “ripe peach,” “peach aftertaste”) and good mouthfeel (“thickness”) without bitter taste notes. In contrast, the single sweeteners aspartame and sucralose exhibited a long “sweetness build” and a pronounced and long-lasting “sweet aftertaste.” Combining these sweeteners with acesulfame K shortened the temporal sweetness profile and diminished the sweet aftertaste.

The taste, cost, and stability of acesulfame K/aspartame blends can be further optimized by targeting the blend ratio for the specific flavorings used. For example, for the orange flavor, no system could totally match the fruitiness of the sucrose-sweetened sample in terms of the attribute “total orange,” but a 30/70 blend of acesulfame K/aspartame, a 17/17/66 blend of acesulfame K/aspartame/cyclamate, or a 30/70 blend of acesulfame K/sucrose came close.

For the strawberry flavor, 30/70 and 50/50 blends of acesulfame K/aspartame achieved the same fruitiness as the sucrose-sweetened sample, while 30/70 acesulfame K/sucrose and 30/50/20 acesulfame K/aspartame/saccharin also achieved good results.

For both the peach and orange flavors, none of the blends containing sweeteners were able to match the fruitiness of the sucrose sample. However, all three combinations of acesulfame K and aspartame (30/70, 50/50, and 70/30) did as well as 30/70 acesulfame K/sucrose, 50/25/25 acesulfame K/aspartame/cyclamate, and 50/25/25 acesulfame K/sucralose, came close.

Thus, a 30/70 blend of acesulfame K/aspartame achieved a high degree of fruitiness for an orange beverage; 30/70 and 50/50 blends for strawberry; and all three blends for peach. By selecting the right blend ratio, the taste profile, sweetness stability, and costs of the total system can all be optimized.

Carbonated Lemon-Lime Beverages

We also evaluated blends of acesulfame K with aspartame and sucralose in carbonated lemon-lime drinks. The goal was to develop sweetener blends that would retain a sucrose-like taste profile over an extended shelf life.

Carbonated lemon-lime beverages using eight sweetening systems (three single sweeteners and five blends) with the equivalent sweetness of 10% sucrose were stored at room temperature for up to 6 mo. At 4, 8, 12, 16, and 24 weeks, a trained panel evaluated samples for flavor, sweetness, chemical and rounded flavor profile, and aftertaste.

While all sweetening systems tested behaved similarly at 4–8 weeks, after longer storage periods the sweetener systems containing acesulfame K outperformed the other blends. Af-

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**Table 2—Expression of cola flavor attributes by selected sweetening systems**

<table>
<thead>
<tr>
<th>Sweetener/blend</th>
<th>“Total cola”</th>
<th>“Spicy”</th>
<th>“Lemon-lime”</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acesulfame K/aspartame (30/70)</td>
<td>++</td>
<td>±</td>
<td>±</td>
</tr>
<tr>
<td>Acesulfame K/aspartame/cyclamate (35/35/30)</td>
<td>++</td>
<td>++</td>
<td>±</td>
</tr>
<tr>
<td>Acesulfame K/sucrose (20/80)</td>
<td>++</td>
<td>++</td>
<td>+</td>
</tr>
<tr>
<td>Acesulfame K/sucralose (20/80)</td>
<td>++</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Aspartame</td>
<td>++</td>
<td>±</td>
<td>±</td>
</tr>
<tr>
<td>Aspartame/saccharin (70/30)</td>
<td>–</td>
<td>±</td>
<td>++</td>
</tr>
<tr>
<td>Sucralose</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Sucrose</td>
<td>+</td>
<td>–</td>
<td>++</td>
</tr>
</tbody>
</table>

*++ system emphasizes attribute very markedly; + system emphasizes attribute; ± system does not support the flavor attribute at all. Cyclamate and saccharin in this table are sodium cyclamate and sodium saccharin.*

**Table 3—QDA attributes for peach flavor**

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sweetness</td>
<td>Represents total sweetness before swallowing</td>
</tr>
<tr>
<td>Onset</td>
<td>Time taken from onset of sweetness to maximum sweetness intensity</td>
</tr>
<tr>
<td>Build</td>
<td>Represents how quickly sweetness is first sensed</td>
</tr>
<tr>
<td>Intensity</td>
<td>Represents total sweetness before swallowing</td>
</tr>
<tr>
<td>Flavor</td>
<td>Represents total acidity before swallowing</td>
</tr>
<tr>
<td>Acid intensity</td>
<td>Total flavor strength of all the peach notes</td>
</tr>
<tr>
<td>Total peach</td>
<td>Flavor strength of the fresh, ripe peach notes</td>
</tr>
<tr>
<td>Ripe peach</td>
<td>Flavor strength of the artificial, stale peach notes</td>
</tr>
<tr>
<td>Artificial peach</td>
<td>Represents total bitterness before swallowing</td>
</tr>
<tr>
<td>Bitterness</td>
<td>A measure of the syrupiness or “body” of the drink in the mouth</td>
</tr>
<tr>
<td>Mouthdrying</td>
<td>The extent to which the drink dries the surface of the mouth</td>
</tr>
<tr>
<td>Mouthfeel</td>
<td>A measure of the syrupiness or “body” of the drink in the mouth</td>
</tr>
<tr>
<td>Aftertaste (20 sec after swallowing)</td>
<td>The extent to which the drink dries the surface of the mouth</td>
</tr>
<tr>
<td>Sweet aftertaste</td>
<td>Total sweetness remaining</td>
</tr>
<tr>
<td>Acid aftertaste</td>
<td>Total acidity</td>
</tr>
<tr>
<td>Peach aftertaste</td>
<td>Strength of peach flavor</td>
</tr>
<tr>
<td>Bitter aftertaste</td>
<td>Total bitterness</td>
</tr>
</tbody>
</table>

*Onset is scored on a scale from “immediate” (0) to “very delayed” (100). All other attributes are scored on a scale from “nil” (0) to “extreme” (100).
nized As Safe, claiming exemption from the premarket or food additive approval requirements. After evaluating the GRAS notification submitted for tagatose, FDA told the manufacturer that it does not object to the manufacturer’s determination of GRAS and that tagatose may thereafter be used in the U.S. food supply.

**Trehalose** is a multifunctional sweetener found naturally in honey, mushrooms, lobster, shrimp and food produced using baker’s and brewer’s yeast. It is commercially made from starch by an enzymatic process. It is metabolized much like other disaccharides. Trehalose protects and preserves cell structure in foods and may aid in the freezing and thawing process of many food products by assisting in maintaining the desired texture. It is also heat stable. It may be used in beverages, purées and fillings, nutrition bars, surimi, dehydrated fruits and vegetables, and white chocolate for cookies or chips. Because it provides 4 kcal/g and is only half as sweet as sucrose, it is more likely to be used for cell preservation than for sweetness. FDA has issued a letter of no objection to the manufacturer’s self-determination of GRAS status for trehalose.

**A Multitude of Choices**

As indicated above, there are many sweeteners from which to choose. Most sweetener suppliers are pleased to provide information on how to best use their products, and some provide model formulations and/or blends or customized products for specific applications.


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**Neotame: The Next-Generation Sweetener**


