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Using Polyols and High Potency Sweeteners

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A recent report by the USDA entitled "Sweetener Consumption in the United States" (August 2005) reports that "US consumption of sugars added to food items increased by 23 percent between 1985 and 1999," although growth in the 21st century seems to have slowed. While refined sugar per capita deliveries grew by 5.3%, high fructose corn syrup deliveries grew by 27.7%. It is interesting to note that - based on this report - 36.3% of sugar and corn sweeteners are consumed in carbonated soft drinks, fruitades, and other nonalcoholic drinks. Versus the 25.4 pounds per year of corn sweeteners consumed in carbonated soft drinks, 5.0 pounds are consumed in cakes, 3.8 pounds in cookies, 4.4 pounds in confectionery, and 1.6 pounds in breakfast-type pastries. Another interesting statistic is that sweetener consumption is highest for the 12-19 year-old age group, consumption then declining with age. Men are guilty of out-consuming women by over 50% in the sweets and beverages category. As reported in previous articles, the 2005 Dietary Guidelines for Americans recommended choosing foods that limit added sugars while balancing caloric intake with physical activity.

Much of the activity around formulating foods with lower sugar and calories has revolved around use of high potency sweeteners, polyols, and fiber. This article will focus on how polyols are used as no-sugar, lower-calorie sugar replacers as well as what high potency sweeteners are available to provide a higher level of sweetness to the product. Since 2002-2004 represented a different trend (the low-carb diet phase), 6-month (March-August 2005) Mintel GNPD product launch data will be used to describe where these products are used in today's market in order to better understand what advantages the food industry sees for each product. The low carb attention served to create greater health awareness among consumers, focusing more attention on product labels. However, if product developers learned anything through the fads of the 1990's and into the early 21st century, they learned that consumers do not want to sacrifice taste for perceived health benefits. Due to better development of new products and ingredients, developers learned that certain products can offer sugar and calorie reduction without sacrificing taste. As a result, new product introductions have continued to steadily grow 2001-2005 in the beverage and confectionery categories, followed to a lesser extent by the bakery and desserts/ice cream categories. As an example, the National Confectionery Association (NCA, Vienna, VA) reports that sugar-free candy sales are up 31%, with sugar-free gum up 9%.

Polyol Principles

What are polyols? I have often heard speakers in symposia refer to polyols as if they were one entity rather than the 9 different product types with some similarities, but other very different properties. Understanding these differences opens up a wide palette of new product development opportunities. The precursors to polyols are sugars which are modified by reducing reactive sites (aldehyde or ketone) through catalytic hydrogenation, enzymatic conversion, or fermentation (or a combination of these). A simple example is the conversion of glucose to sorbitol through catalytic hydrogenation. Although technically polyols are not "saccharides" or "sugars," it is best to describe their molecular size on the same basis as saccharides:

Monosaccharides	Disaccharides	Polymeric Mixtures
Sorbitol	Maltitol	Maltitol Syrup
Mannitol	Isomalt	
Xylitol	Lactitol	Polyglycitol (HSH)
Erythritol		

The polymeric mixtures - maltitol syrups and polyglycitols - are basically the "corn syrups" and "maltodextrins" of the polyol group. All polyol mixtures can be broadly referred to as "polyglycitols," but if the % maltitol (on a dry weight basis) is greater than 50, the mixture is a "maltitol syrup." The functional and chemical properties of polyols are very different, and developers need to understand where these properties function best. A good reference chart for comparative properties can be found at www.spipolyols.com. In comparing polyols, one must consider differences in sweetness, solubility, cooling effects, molecular weight, and laxation potential among other things. Polyols range in sweetness from 0.3 – 1.0 times the sweetness of sugar, as noted below:

Polyol	% Sweetness Relative to Sucrose
Xylitol	100
Maltitol	90
Maltitol Syrups	70-80
Erythritol	60
Sorbitol	60
Mannitol	50
Isomalt	40
Polyglycitol	30-50
Lactitol	30-40

In some applications, depending on the polyol, there may be no need for additional sweetness. If additional sweetness is required, this is where polyols and high potency sweeteners work well together. Their sweetness levels can sometime be synergistic, and the polyol can often moderate the sweetness profile of the high potency sweetener. It is important to note, however, that some crystalline polyols produce a cooling effect as they dissolve. This "heat of solution" is an actual exchange of energy which lowers or raises the temperature of the solution as the polyol dissolves. This heat of solution is measured in calories or joules per gram, and can be a negative (cooling) or positive (heating) value. Sucrose in crystalline form produces a very slight cooling effect at -4.0 cal/gram. Compare this to erythritol at -42.9 cal/gram, xylitol at -36.6 cal/gram, mannitol at -28.9 or sorbitol at -26.5. The cooling effect becomes closer to sucrose through lactitol (-14.9 cal/gram), isomalt at -9.4, and finally maltitol at - 5.5 cal/gram. In order to use the polyols with the highest negative heat of solution in something like a chocolate coating, this effect must somehow be moderated with a higher molecular weight polysaccharide or a carbohydrate with a positive heat of solution (e.g. glycerin). "Solubility" is the amount of solute (sugar or polyol) that can be dissolved into a solvent (water) at a given temperature before it becomes saturated. The % of solute can increase if temperature is increased, but if the saturated solution is cooled, the solute will begin to fall out of solution, typically in crystal form. This is the principal behind "graining" in confections - a positive attribute when controlled to form the basic textures and appearance we expect in confectioneries, but a negative when uncontrolled - leading to appearance and texture problems in confectionery, nutritional bars, baked products, frozen desserts and ice cream, beverages, etc. Since detriments are often caused by shelf life conditions and can lead to customer complaints, understanding the solubility of your sweetener system is very important. The solubilities of crystalline polyols are shown here

Sweetener	Solubility at 25° C (g/100g H2O)
Sorbitol	235
Xylitol	200
Sucrose	185
Maltitol	175
Lactitol	140
Erythritol	61
Isomalt	29
Mannitol	22

Mannitol, isomalt, and erythritol are the least soluble and crystallize most readily – an attribute which works well in low moisture products or products requiring rapid crystallization or low hygroscopicity. Mannitol, for example, is often used as a dusting agent or tablet excipient. Isomalt forms a hard, stable crystal which is used extensively in hard candies and lozenges to prevent "cold flow" and stickiness. Uncontrolled, it can form a white, coarse crust around the candy. This is often controlled by a crystallization controller, or "doctoring agent," often a high molecular weight maltitol syrup or polyglycitol. Lactitol, maltitol and xylitol are closer in solubility to sucrose, so that they crystallize similarly (although not at the same rates). Maltitol and lactitol in crystalline form are relatively non-hygroscopic, so they perform well in systems like chocolate compound coatings or icings. Xylitol is more hygroscopic and has a tendency to clump if exposed to moisture – which can cause problems in coatings or icings. Sorbitol is extremely soluble, and is often used for its humectant properties or as a plasticizer in confectioneries and chewing gums.

The molecular weight of polyols is an extremely important consideration in their application – its effect can impact viscosity, texture, starch gelatinization, freezing point, osmolality, and boiling point (to mention a few effects). Molecular weights of polyols are listed below in descending order:

Sweetener	Molecular Weight (g/mol)
Polymer mixtures:	
Polyglycitol	Variable
Maltitol Syrup	Variable
Corn Syrups	Variable
Disaccharides:	
Lactitol	362.3
Isomalt	344.2
Maltitol	344.2
Sucrose	342.0
Monosaccharides:	
Mannitol	182.0
Sorbitol	182.0
Xylitol	152.2
Erythritol	122.0

For the syrups, as average molecular weight increases (remember that maltitol syrups are >50% maltitol), viscosity increases, sweetness decreases, water activity decreases, and binding capability (for baked and extruded products, for example) increases. As molecular weight decreases in the polyol range, osmolality increases in solution, the freezing point decreases, starch gelatinization temperatures decrease, and boiling point increases. How can this impact product? Molecular weight can significantly impact cookie spread, cake volume, pie filling boil-outs, ice cream texture/shelf life, and beverage stability and palatability.

The Polyol/Fiber Connection

Is laxation an issue? Polyols have been an important component of sugar free confectionery for many years, and can be used effectively to reduce sugar and calories, lower blood glucose response, and to formulate tooth-friendly, non-cariogenic confections. Like fiber, polyols are low-digestible carbohydrates. Like fiber, what is not absorbed in the upper gastrointestinal tract can, at certain threshold levels, lead to osmotic imbalance or fermentation, resulting in loose stools and gas. This effect is highly variable, and can vary from person-to-person, so exact thresholds are hard to establish. Approximate values on a grams/day basis are:

Sweetener	Laxation g/day
Erythritol	125
Sucrose	>100
Polyglycitol Syrup	>100
Maltitol Syrup	>100
Maltitol	90
Fructose	70
Isomalt	50
Sorbitol	50
Lactitol	20-50
Mannitol	20

In the US, an "excessive consumption may cause laxation" warning must be placed on the label if the product could lead to >20 gm/day consumption for mannitol or >50 gm/day consumption for sorbitol. No other polyols are specified, so it is left to the discretion of the manufacturer. It is important to note that a single-dose serving of any polyol exceeding 30-50 grams could cause minor discomfort. Since consumers have been known to consume more than one serving, a "safety zone" rule of use should be:

- Less than 15 gm/serving for disaaccharide polyols
- Less than 20 gm/serving for polysaccharide polyols

In most categories, it is easy to formulate excellent products within these guidelines using other ingredients such as fiber and gums (as well as sucrose!) to formulate the best product. As long as polyols are used as a part of the overall "ingredient toolbox" to formulate products with improved nutrition, laxation is not an issue.

Using Polyols – Proof in Practice

And now for something completely different – I thought it would be interesting to look at Mintel's product launch database for the past 6 months to observe where polyols are being used in the post-low carb market. On a global basis, there have been greater than 2000 product launches in the March-August 2005 period utilizing polyols, about 50% of these within the U.S. and Japan. Where are these polyols used? First, you need to understand that the food market for polyols is less than 50% of the total global demand, and sorbitol use far exceeds the use of any other polyol. Worldwide, polyols are used in confectionery, oral hygiene, skincare, healthcare, bakery, snacks, soap/bath products, hair care, desserts/ice cream, and shaving/depilatory products. Of the global >2000 launches in March to August 2005, about 400 were in confectionery, which is the largest market for polyols in the food segment. Focusing in on the U.S., sorbitol is still the most widely-used polyol – especially as a 70% solids product, as it is on a global basis. Within the 6 month period, there were 266 product introductions noted, primarily within healthcare, confectionery, and desserts and ice cream. Orbitol is used extensively as a non-sugar bulking agent in mouthwash, toothpaste, chewing gum, and no-sugar-added ice cream. Maltitol was involved in over 60 product introductions within the 6 months – primarily in confectionery and snacks, followed by desserts and ice cream, as well as baking. Maltitol's high level of sweetness and chemical/physical similarity to sucrose are responsible for its popular use in chewing gum coatings, chocolate, nutritional bars, ice cream, and bakery applications. Mannitol was next, with about 40 introductions, primarily in healthcare, confectionery and desserts and ice cream. It is commonly used as a table excipient, a dusting agent and/or plasticizer in chewing gum, and as a sucrose replacer in chocolate coating for ice cream.

Xylitol had 35 product introductions in the 6-month period within confectionery, healthcare, and oral hygiene. Xylitol has well-documented support as a cariostatic tooth-friendly polyol which eliminates dental plaque and re-mineralizes enamel, so it is extensively used in chewing gums and toothpastes. Its cooling effect is viewed as a positive benefit in these applications. Maltitol syrup was involved in over 25 new product introductions in the period, primarily within snacks, confections, ice cream, and bakery. Remember that maltitol syrups are the "corn syrups" of the polyol group, providing viscosity, binding and humectancy (as well as sweetness) to nutritional bars, soft candies, caramels, and other inclusion products. Maltitol syrup also replaces corn syrups as bulking agents, sweeteners, and freeze point/crystallization control in ice creams. Lactitol was involved in about 20 new introductions – primarily within ice cream and nutritional bars, where it could be found primarily in sugar-free inclusions. Isomalt was involved in 15 new product launches within the confectionery and healthcare categories. As previously mentioned, isomalt forms a very stable crystalline structure in hard candies as well as lozenges and cough drops, so it is often found in these applications, often paired with a maltitol syrup as a "doctoring agent." Erythritol was included in >10 product launches within the period, primarily with confectionery, bakery, and ice cream categories. Because erythritol is fermented with no chemical hydrogenation step, it is considered as "natural", and is often used within natural applications. In addition, erythritol contributes only 0.2 kcal/gm, and has a very high laxation threshold. Polyglycitols (hydrogenated starch hydrolysates) were involved in one product launch – a soft candy application. Polyglycitol syrups are the "low DE and maltodextrin" segment of the polyol group, and are primarily used for their stability in hard and soft candy applications.

A look across the industry reveals the broad use of polyols beyond merely "sugar-free for diabetics" as they are commonly viewed. Polyols are used for their tooth-friendly properties, their "slow metabolism," low glycemic index, reduced caloric density, viscosity, color and flavor stabilization, compressibility (tablets and mints), plasticity, control of colligative properties (freeze-point, boiling point, osmolality), water activity control, binding properties, candy and inclusion stability, non-hygroscopicity, and prebiotic properties as well!

Upping the Sweetness

In March 2005, the Calorie Control Council (Atlanta, GA) released a report on new research conducted by Dr. Madeline Sigman-Grant, Ph.D., R.D. at the University of Nevada. Her research, based on more than 1,000 adults, found that those who incorporated reduced-caloric products consumed more vitamins and minerals in their diets. Dr. John Foreyt, professor at Baylor College of Medicine, was optimistic, stating "many people slash calories drastically when trying to lose weight and end up missing out on important vitamins and antioxidants. However, this research demonstrates that people can reduce calories while continuing to have a high quality diet. An easy way to do this is through the use of products containing low-caloric sweeteners." The American Dietetic Association and the American Diabetic Association have further supported the use of a range of nutritive and non-nutritive sweeteners in their position statements on sweeteners (http://www.eatright.org/Member/PolicyInitiatives/index21018.cfm and http://www.diabetes.org/nutrition-and-recipes/nutritional/sweeteners.jsp).

In considering high potency sweeteners, the list could be extensive, including cyclamates, saccharin, aspartame, acesulfame potassium, neotame, sucralose, stevioside, thaumatin, neohesperidin dihydrochalcone, lo han guo, and glycyrrihizin to name a few. These have been covered in previous articles, which can be found in the Food Product Design archives at http://www.foodproductdesign.com. This discussion will cover some current information on the major high potency sweeteners in the market today – this would include (on a volume basis) cyclamates, saccharin, aspartame, sucralose, and acesulfame potassium (K), as well as neotame as an approved (US) sweetener with emerging interest.

Saccharin was first discovered in 1879 and is the most widely used on a global basis. Saccharin is approximately 300-500 times sweeter than sugar, but suffers from a metallic aftertaste. Although hampered in the US for many years by regulatory concerns, saccharin is the low-cost high potency sweetener, resulting in wide-spread use on a global basis. Cyclamate, discovered in 1937, is 30-50 times sweeter than sugar, but suffers from similar problems (aftertaste and regulatory) in the US. Although not permitted in the US, cyclamate is permitted in more than 50 countries. Again using Mintel product launch data for March-August 2005, >2000 new product introductions were noted globally for the 6 sweeteners discussed, and >390 introductions in the US. Of the global introductions, >550 were attributed to saccharin (96 introductions in the US). The global introductions were dominated by the US and Japan. Where is saccharin found? Cosmetics and skincare (lipstick, lip balm, etc.), oral hygiene (mouthwashes, toothpastes) and healthcare (cough syrups, etc.) dominate the categories. Next time you are in the drugstore, take a look at these products on the shelf to appreciate the wide use of this sweetener. Cyclamates were involved in >130 global introductions, primarily in beverages (Germany, Netherlands, Brazil, China), dairy (Germany, Brazil), and snacks (China).

In the 1960's, two sweeteners were developed which contributed significantly to the "boom" in new diet and sugar-free products – especially in the US market. Aspartame, discovered in 1965, is about 180 times sweeter than sugar. Aspartame is noted for a slow sweetness onset and a lingering sweetness. Stability is good in most applications, but can be affected by temperature/moisture/pH/time considerations, but aspartame has now been in use for over 30 years, so its limitations and ideal conditions are well understood. Although aspartame's safety has been supported by numerous clinical studies, consumer perception has often been affected by periodic media reports – the latest based on an Italian study currently under scrutiny by the European Food Safety Authority (EFSA). However, as noted by Lyn Nabors, newly-named president of the Calorie Control Council, "with billions of man-years of safe use, consumers and health professionals can be assured that aspartame is safe for humans, and the rigorous scrutiny and battery of studies to which aspartame has been subjected should provide people with additional confidence in its safety." Acesulfame potassium (Acesulfame K) has a similar sweetness (200 x sucrose), but a more rapid onset, less lingering, but a bitter aftertaste. Acesulfame K also has better stability than aspartame and has mostly avoided consumer issues. Nutrinova, Inc. (Somerset, NJ), supplier of acesulfame K, has worked hard to feature the product's synergy with aspartame and sucralose in applications. Acesulfame K's fast onset, quick clearing, and stability characteristics complement aspartame's slower-onset, lingering and variable stability, providing a more optimized sweetener system. This was emphasized at the July 2005 IFT by Nutrinova's Jean Ann La Spada, food technologist, and Bill Riha, head of regulatory and scientific affairs. La Spada emphasized that, in most cases, acesulfame K blends provided a higher flavor and sweet scores earlier in chewing gum tasting, along with prolonged flavor and sweetness. Riha reported on comparisons of blends of acesulfame K/aspartame/sucralose in a berry-flavored chewing gum. Studies showed that a 30/70 acesulfame K:aspartame gum was higher in sweetness and berry flavor than other blends or aspartame alone.

Where did these products see success in the Mintel March-August 2005 time period (within the US only)? Aspartame was involved in about 90 new product introductions, primarily in confectionery, beverages, healthcare, and desserts and ice cream. Aspartame is still used extensively, often with acesulfame K, in chewing gum, and this is seen within the database. According to Brendan Naulty, vice president, sales and marketing, Ajinomoto Food Ingredient LLC, Chicago, IL, "aspartame has been used for about 20 years in frozen dairy applications, and continues to be used extensively in new products in that category – it works well." It is not surprising to find acesulfame K in 141 new introductions, all in the same categories reported for aspartame. It is interesting to note that – in the beverage category – Coca Cola has differentiated its products based on sweeteners. Diet Coke contains aspartame, Coca-Cola Zero has aspartame and acesulfame K, and Diet Coke with Splenda was recently introduced. Many of the sugarless gums introduced in 2005 have featured the aspartame/acesulfame K combination.

Sucralose, discovered at Queen Elizabeth College at the University of London during the 1970's, has enjoyed enormous popularity following its US approval as an all-purpose sweetener in 1999. According to Mintel reports, Splenda usage has increased 126% over the past two years, with 458 launches Jan – June of 2005 compared to 942 food and drink launches for total sweeteners. Let's state it right up front – sucralose is derived from sucrose in a procedure that substitutes chlorine atoms for hydroxyl groups on three sites. It is not sugar, and is not "natural." It is 600 x sweeter than sugar with excellent stability

in foods. Sucralose has a slow onset with a lingering sweetness – in many applications, sucralose is used by itself, but it can also be found in combination with other sweeteners. Within the March – August 2005 time period (US only), sucralose has been part of over 200 new product introductions, almost half of these in beverages. Other categories represented are ice cream, confectionery, snacks, dairy, healthcare, and oral hygiene. Although clearly not the low-cost sweetener, sucralose is enjoying a positive consumer image created by a creative and detailed market approach. Continued focus on direct consumer sales has continued to provide benefits to business-to-business sales.

The new sweetener on the block is neotame, approved in the US in 2002. Neotame, developed in the 1990's, is manufactured from aspartame and 3,3-dimethylbutyraldehyde via reductive alkylation. The result is a sweetener 8,000 times sweeter than sugar with no phenylketonurics warning labeling required. On a sugar equivalent cost basis, neotame is second only to saccharin as a low-cost sweetener. Neotame is recommended – not as a primary sweetener - but in blends with other high intensity sweeteners or as a substitute for 20% of the high fructose corn syrup and sucrose in formulations. Mintel new produce launch data indicate that neotame has been involved in new product introductions in the US (primarily), New Zealand, Australia, Vietnam and Malaysia. Primary categories have been beverages, confections (primarily US), and small launches in snacks and dairy. Within the March – August 2005 period, neotame has been launched in several extensions of flavored milk and in a couple of chewing gum applications. In these applications, it has been combined with other high potency sweeteners.

Another more "natural" route to sweetness has been taken by Roxlor International LLC, Wilmington, DE. According to Robert M. Veghte, president "we have a new sweetener system based on oligofructose, fructose, and a proprietary sweetening system that uses natural flavors and citrus extracts. This product, 10 x sweeter than sugar, allows you to add the additional sweetness required when using polyols without needing to add high intensity sweeteners to your label." Roxlor's other products, also based on oligofructose, fructose and inulin, also include a mung bean extracted sprouted in a nutrient medium containing acesulfame K. Benefits are inclusion of fiber in a sugar free system which is also reduced in calories.

As consumers continue to recognize the benefits of a reduced sugar(s), reduced calorie diet combined with increased fiber, good fat choices and appropriate portion sizes (and don't forget exercise!), choices within the "ingredient toolbox" continue to improve. As sugars are reduced and fiber is increased, polyols are required to maintain the molecular weight profile of the sweetening system so that texture and shelf life are not sacrificed. High potency sweeteners are required to deliver the sweetness equivalent to that in a full-sugar type of product. The consumer expects health benefits and indulgence in the same foods. Is this achievable? YES! Any movement in the right direction is a positive change – nobody said that foods need to be all fat-free, sugar-free, and 100% of the RDA for fiber. Consumers have seen these and sent them back to the drawing board. The key is health benefit improvement that is obvious on the label, not in the product quality.

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