

Review Articles

The Sweetness Technology of Sugar Substituted Low-Calorie Beverages

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Abstract

A perturbing increase in the number of diabetics and obese people in all age groups of the population has raised concern in the scientific and industrial community to develop low calorie or no added sugar beverages. Nowadays such sugar-free beverages are gaining popularity because of their inherent thirst quenching properties and fewer calories. Production of such beverages has been possible with the replacement of sugar and incorporation of artificial sweeteners which are low/free in calorie content. The sweetness technology for low-calorie beverages has attained strong commercial success with the safe use of non-nutritive sweeteners that deliver good taste quality. However, some considerations for their efficient use include their solubility and stability in beverage systems along with cost effectiveness. The assessment of non-nutritive sweeteners shows that high-potency artificial non-caloric, include synthetic sweeteners, i.e. aspartame, acesulfame-K, Cyclamate, Neotame, Saccharin and Sucralose whereas natural ones embrace Stevia and Monk Fruit extract. Each one has limitations for taste quality if used singly, i.e., short maximal sweetness response, “off” tastes or/and fast/slow-onset of sweet tastes. However, if used in combination their sweetness intensity increases and taste profile matches the sucrose. The beverage taste profile varies depending upon the type and combination of sweeteners. Optimum blend ratios harmonize the taste profile of specific flavor of beverage and are best determined by sensory testing various blends.

Introduction

The food industry is frequently seeking to augment nutritional value of many foods and beverages by adding different functional components like soluble and insoluble dietary fibers, phytochemicals, antioxidants, probiotics, vitamins, minerals, and many others. The health-conscious consumers demand newer specialty products, without disturbing the natural nutritional attributes [1]. The society today is becoming aware of maintaining its health rather than relying on expensive medical treatments [2]. The calorie-conscious nature of diabetic and obese consumers has obligated the food and beverage industry to develop products with low calorific value [3]. Hence, the low glycemic foods are gaining more attention because of a lower risk of developing obesity and type-2 diabetes [4] as these greatly increases the risk of heart disease and stroke. Type-2 or non-insulin dependent diabetes can be delayed or managed through exercise and diet modifications, especially the type of carbohydrates [5,6].

A sweetener is naturally occurring or synthetically produced substance that develops a sweet taste in drinks. The replacement of natural carbohydrate based sweetener (sucrose or high fructose

corn syrup/HFCS) with low calorie or high-intensity sweeteners is a novel approach to developing specialty beverages [7]. Sucrose (table sugar) is regarded as the “gold” standard for sweet taste and is the most common sweetener in the beverage industry. Sweeteners are commonly classified as nutritive or non-nutritive. Nutritive or caloric sweeteners are usually made from fruits, sugar cane, and sugar beets which on an average provide four Calories/g [8]. Unlike sugar and other carbohydrates, non-nutritive or high-intensity sweeteners provide sweetness along with little or no calories when metabolized. Some of the non-nutritive sweeteners are not metabolized and are excreted unchanged by the body [9] whereas several others are metabolized in part, and their metabolites are readily excreted [10]. Non-nutritive sweeteners have been considered as good sugar substitutes in food applications, especially in beverages which are the primary sources for sugar intake [11].

Most of the consumers normally select functional or specialty beverages for achieving some health benefits [1]. This reason has prompted the use of high-intensity artificial sweeteners (saccharin, aspartame, acesulfame-K) and natural sweeteners (stevia) with low or no calorific value as sweetening agents in foods

[12]. In the past, artificial sweeteners were used mostly in diabetic products, but now they have become more popular as alternative sweeteners in contemporary processed food products especially in soft drinks and other beverages [13]. The quality of food not only depends on nutrients but also on other substances such as food additives, the presence of which could be justified, allowed or tolerated only when they are harmless to the health [12].

The sugars obtained from carbohydrate sources has a significant regulating effect on the overall taste sensation. However, replacement of carbohydrate-based sweeteners like corn syrup, glucose, fructose and sucrose from the beverages with high potency sweeteners is one of the most appropriate solutions but poses several sensory and technical challenges [1] due to lowering of solids contribution [14]. The improvement could partly be realized by the use of low-calorie bulk fillers/ bulking agents i.e. polydextrose, maltodextrins, and many others [15] along with the use of stabilizers to enhance the overall mouth feel of the beverages. Due to these features, rare sugars are also desirable for fewer calories and bulk sweetener as well. These sugars provide desirable sweetness but don't get metabolized in the human body and therefore do not provide calories [13].

The main category of non-nutritive sweeteners is an artificial sweetener, which has been introduced into the market for a long time. However, with the increasing concern for health and fitness, the beverage industry tends to use artificial sweeteners based on the consumer's demand. However, there is no complete acceptable low-calorie substitute for sucrose available to consumers [16].

Non-nutritive sweeteners- Artificial and Natural

The non-nutritive sweeteners are known to be 30 to 13,000 times sweeter than sucrose [17]. The increased incidences of obesity and similar health issues correlated to nutritive sweeteners resulted in an increased demand for sugar-free/reduced-sugar foods. The non-caloric sweeteners differ from nutritive sweeteners in taste, sweetness potency, temporal profile and taste defects such as bitterness, metallic and liquorice-like tastes [18]. Acesulfame-K, aspartame, saccharin, sucralose, etc. are artificial sweeteners approved by the FDA [9]. These could be utilized in foods and beverages individually or in combination depending on their sensory profiles [19]. Stevia extract (stevioside, rebaudioside A) and Monk Fruit extract are two natural non-nutritive sweeteners which are identified as "generally recognized as safe" by the FDA [9]. These natural high potency sweeteners gained importance in the beverage world due to more consumer acceptance for natural additives and or ingredients [20]. The taste profile of high-intensity sweeteners is claimed to be more acceptable if used in blends due to their disagreeable tastes [21].

Acesulfame-K

Acesulfame-K is a combination of an organic acid and potassium. It is almost 200 times as sweet as sucrose when used at

moderate sweetness levels. The sweetness is perceived quickly as compared to aspartame and sucralose [22]. It could have a bitter after taste when used alone in food or beverage [23] Therefore, combining it with other non-nutritive sweeteners is a common remedy for its practical applications. Also, its high heat stability allows its extensive use in beverages. It is not metabolized in humans or other animals [24] or by bacteria of the oral cavity or intestine when added either in combination or individually [25], therefore, about 95% Acesulfame-K is excreted unchanged in the urine [26]. Thus it can be used for low-calorie and diet beverages due to its sound stability in aqueous solutions even at low pH typical of diet soft drinks.

Aspartame

Aspartame is a methyl ester of aspartic acid and phenylalanine dipeptide. It has a clean, sweet taste and is approximately 180-200 times sweeter than sucrose. Unlike other high-potency sweeteners, its sweetness profile is similar to sucrose, with a slightly longer onset time and a lingering taste which may be improved by blending with other sweeteners [27]. It is stable under dry conditions, but in solution, it degrades during thermal processing. The rate of degradation depends on pH and temperature [28]. The intake of aspartame in food stuff decreased the glucose level [29].

Aspartame is used in many areas of the food and pharmaceutical industries, especially in soft drinks. However, due to its low thermal stability, it is not suitable for baked goods. The phenylalanine being one of the breakdown products of aspartame, it is important to consider its intake for consumers with phenyl ketonuria [30]. For this reason, products using aspartame are required to reveal on their packages that it contains a source of phenyl ketonuria. Aspartame is not fermented by tooth plaque bacteria and therefore is considered to be tooth friendly [31].

Cyclamate

Cyclamate is a salt of cyclohexyl sulfamic acid. Cyclamate is 30 times sweeter than sucrose. Sodium cyclamate is used as a sweetener, and its analogous calcium salt is employed in low sodium diets. It has a bitter off taste but has good sweetness synergy with saccharin. It is soluble in water, and its solubility can be increased by preparing the sodium or calcium salt [32]. Cyclamate is least toxic in nature if not transferred to the gut but if metabolized by the gut bacteria, shows greater toxicity due to the formation of cyclohexylamine during its metabolism [32].

Neotame

Neotame is a derivative of aspartame, a dipeptide compound of the amino acids, aspartic acid, and phenylalanine. It is approximately 8,000 times as sweet as sucrose and has a clean, sweet taste but an apparent licorice aftertaste at high concentrations [33]. Its degree of sweetness varies according to the kind of food and blend composition [34]. It is an odorless white to gray-white powder, slightly soluble in water and readily soluble in alcohols. The aque-

ous solution (0.5%) of neotame is weakly acidic (pH 5.8) [34]. It is as stable as aspartame in many food products and is more stable at neutral pH than aspartame. It is not metabolized by oral bacteria and is excreted in the urine and feces [27].

Saccharin

Saccharin is a non-nutritive sweetener of 1, 2-benzisothiazol-3-(2H) on 1,1 dioxide. It is 300-500 times as sweet as sucrose, with a similar sweetness temporal profile. However, it has significant bitter and metallic taste, resulting in an appropriately blended application. Sweetness synergy of saccharin with other sweeteners is not universal and predictable [35]. Saccharin is very stable under all conditions in food applications. It is slowly and incompletely absorbed from the small intestine and is not metabolized in humans [18]. The major applications of saccharin are in beverages, either in finished products or as a tabletop sweetener.

Sucralose

Sucralose is a disaccharide comprising of three chlorine molecules replacing three hydroxyl groups on the sucrose molecule [36]. It is 450-650 times sweeter than sucrose. It has a pleasant sweet taste and its quality and temporal profile is very close to sucrose, has neither a bitter aftertaste nor a metallic taste. It has good sensory profile that makes it suitable either individually or in a blend with other sweeteners [37]. It has a reasonable synergy with other nutritive and non-nutritive sweeteners. It is also said to be non-cariogenic [38]. It has an excellent stability during heating and in low and neutral pH. It can be widely used in various foods and beverages, including baked products. Most sucralose (85%) is not absorbed and is excreted unchanged in feces. The absorbed sucralose is excreted unchanged in urine [39].

Stevia Extract (Steviol glycosides)

Steviol glycosides are extracted from leaves of the plant *Stevia Rebaudiana* Bertoni. Stevioside and Rebaudioside A are the main constituents in extracts, expressing high sweetness intensity [40] and are also known as bio-sweeteners [41]. These are shelf stable in solid form and have better stability than aspartame and acesulfame-K in liquid form. In the beverages, both of these show excellent stability under normal conditions, whereas chemical degradation occurs under extreme conditions of high temperature and pH [42,43]. There is no evidence of steviol accumulation in the body from successive ingestions [44]. Nutrition and toxicity studies indicated that either Stevioside or Rebaudioside A does not pose a serious health threat in various animals [45].

Monk Fruit Extract

Monk Fruit extract is a natural high-intensity sweetener, also known as Luo Han Guo. This is a combination of several different cucurbitane glycosides, known as mogrosides [46]. It is 150 to 300 times more sweet than sucrose depending on the structure of the

mogrosides, the number of glucose units and the food matrix [40]. Since Monk Fruit extract is the latest sweetener discovered for applications in foods, there are only a few investigations conducted on the flavor profile and physio-chemical properties, both of which are vital in suggesting the practical applications.

Rare sugar

Rare sugars are monosaccharides and their derivatives that rarely exist in nature [47], for example, D-psicose, Tagatose, D-allose, and others [13] these sugars possess the properties like sweeteners but lack calorific value. Therefore, these could be used as an alternative to other sweeteners. Rare sugars are not metabolized as natural sugars by the body [48]. These have recently engrossed lots of consideration mainly for their applications in food and beverage industry.

Applications in beverages

Beverages are considered to be essential items of human diet because of their stimulating and refreshing nature and sufficient liquid content. These are used all over the world for their revitalizing qualities. Man's earliest beverage was probably the juice squeezed from fruits, but the civilized man discovered a vast collection of beverages for his enjoyment and nutrition. The health and nutritional concerns have led to increased demand for functional beverages that provide additional health benefits. Many options are now surpassing traditional beverage market; the trend is likely to continue as is the growing demand for innovative ingredients.

Dairy based

Whey is a major dairy by-product obtained in the manufacturing process of paneer, channa, cheese and casein. Whey consists almost 50% of total solids present in the milk and is a valuable source of lactose, proteins, minerals, and vitamins. The production of whey beverages is one of the most economically feasible options of whey utilization. Based on pH value, whey protein beverages fall into two categories. One is the shake-type, pH between 4.6 and 7.5 and the other is acidified whey protein beverages with a pH range of 2.8-3.5 [49]. Some whey protein beverages comprising functional beverage with high protein content included inulin and stevia [50] whereas a whey lemon beverage incorporated a blend of aspartame and saccharin [51]. Aspartame and acesulfame-K might be suitable as total sugar replacers in whey beverages, resulting in an appreciable reduction of the amount of carbohydrate. The amount of each sweetener required to produce a sweetness level equal to that of a beverage containing 10.5% invert sugar was found to be 0.25 and 0.275 g aspartame and acesulfame-K/liter, respectively. When used together, both exhibited their synergism, resulting in a 25% reduction of the total sweetener required. Heat treatment of 30 min at 90°C did not cause a noticeable decrease in the sweetness or taste quality.

Aspartame, acesulfame-K, and their blend were assessed for stability during storage in a whey-lemon beverage by [52]. The increase in acidity and viscosity and a decrease in pH and ascorbic acid content of sweetened whey-lemon beverage samples were similar to the those in control. Aspartame (added either singly or in a blend) and acesulfame-K (added in a mixture) were stable in the beverage under the refrigerated condition for 15 days. Another functional Whey-Lemon Beverage (WLB) was formulated using combinations of aspartame and saccharin. The blend of these sweeteners (70:30, 0.0425%) scored highest organoleptically as compared to only sweetener aspartame (0.07%). The blend showed maximum synergy in sweetness intensity (14.4%) and overall acceptability (7.5%) as compared to aspartame alone. The multi-sweetener approach involving the use of binary blend resulted in 39% reduction in usage level as compared to a single sweetener [51].

The flavored functional milk drinks were prepared by replacing 0 to 100% sugar with sucralose and adding 4% inulin in the milk of 0.5% fat and 8.5% solid-not-fat. Sugar replacement considerably decreased total solids, total soluble solids, viscosity and sensory scores. Moreover, the calorific value diminished by 43% in the experimental milk drink compared to control [53]. Furthermore, experimentation on assessment of the stability of the pasteurized drinks showed that the Total Solids (TS) and pH dropped while the Total Soluble Solids (TSS), titratable acidity and viscosity amplified with storage [54].

In a fermented milk beverage (lassi) [55] applied sweetener blends. The levels of sweeteners were optimized either individually or in combination with each other based on the organoleptic assessment. Aspartame and acesulfame-K in combination scored the highest when compared with the aspartame alone. Binary blends resulted in 38% reduction of only sweetener, aspartame.

Li et al. (2015) [56] conducted a study to recognize the sweetness intensity perception of Stevia Leaf (STV) and Monk Fruit (MK) extracts and to evaluate these as a sweetening agent in Skim Chocolate Milk (SCM). They found that chocolate milks sweetened with stevia leaf and monk fruit extracts in combination with sucrose were acceptable both by young adults and children. The milks solely sweetened by nonnutritive sweeteners were less acceptable compared to control (sucrose) by young adults. The information of chocolate milk presented on the label also influenced parental acceptance. Traditional parents preferred sucrose-sweetened SCM, whereas label conscious parents preferred SCM with natural nonnutritive sweeteners.

Juices

Larson-Powers and Pangborn (2006) [57] conducted several experiments for the selection of artificial sweeteners by two descriptive sensory methods. Different sweeteners were used in

strawberry, lemon, and orange drinks, and strawberry drinks. The samples having sodium saccharin scored lower than the sucrose, while aspartame obtained minimum whereas calcium cyclamate was found to be intermediate. Orange drink was prepared by using stevia, whereby 25 to 100%, sugar was replaced by Rebaudioside A. Ardali et al. (2014) [58] observed that as the amount of Rebaudioside A increased in the formulation of the drink, the turbidity increased but Brix, pH, and specific gravity decreased. The color measurement of the sample indicated that its increasing amount increased L value but a*, and b* value did not differ significantly. The sensory scores of sample augmented considerably in the sample as the Rebaudioside A level increased up to 100%. It was found to be a real sugar replacer in orange drink formulation. Orange nectar prepared using sucralose, as a partial replacement of sucrose was studied by Al-Dabbas and Al-Qudsi (2012) [59]. Raspberry beverages sweetened with aspartame/acesulfame potassium blends had balanced sourness and astringency. The sweetener blend ratio had no effect on flavor/mouthfeel attributes. The artificially flavored beverages contained 50/50 to 80/20 aspartame-acesulfame-K ratio [60]. Three intense sweeteners namely aspartame, acesulfame-K, and sucralose were included singly in the lime-lemon flavored carbonated beverage. The loss of aspartame was more (29.5%) than acesulfame-K (6.1%) followed by sucralose (1.9%) after 60 days' storage at 37°C. Sucralose was more stable than the other sweeteners [61]. De Marchi et al. (2009) [62] optimized the levels of sweetener for the acceptability of a natural passion fruit beverage using sucrose and equi-sweet concentrations of aspartame, sucralose and a blend of aspartame and acesulfame-K (80% and 20% respectively). The concentrations of aspartame, sucralose and a mixture of aspartame and acesulfame, selected on sensory basis were 0.043, 0.016 and 0.026% respectively. The effect of different sweeteners on the sensory profile and acceptance of passion fruit juice samples sweetened with some natural and artificial sweeteners including their blend was studied. It showed that samples with sucrose, aspartame and sucralose had a similar sensory profile without bitter taste, bitter aftertaste and metallic taste and samples with sucrose and sucralose did not differ from each other for the attribute sweet aftertaste. The samples containing with aspartame, sucralose, and sucrose presented higher acceptance scores for the flavor, texture and overall acceptability, with no significant differences between them. Aspartame and sucralose were found to be good substitutes for sucrose in passion fruit juice [63].

The sucrose was replaced in acerola nectar with different sweeteners namely neotame, sucralose, stevia and rebaudioside A with 40%, 60%, 80% and 95%, respectively [64]. Freitas et al. (2014) [65] developed pitanga nectar in which sucrose was replaced with different sweeteners to obtain same sweetness intensity with fewer calories. With the ideal pulp dilution of 25% and the perfect sweetness using 10% sucrose, sweetener concentrations to replace sucrose were 0.0160%, 0.0541%, 0.1000%, 0.0999%,

0.0017%, and 0.0360%, respectively, for sucralose, aspartame, stevia 40% rebaudioside A, stevia 95% rebaudioside A, neotame, and a 2:1 cyclamate-saccharin blend. The peach nectar was formulated by considering the appearance, aroma, flavor and overall liking. The liking values were highest for samples combining the two sweeteners, aspartame and acesulfame-K confirmed the synergistic effect and allowed cost reduction as well as additives intake, without compromising the sensory characteristics [66]. Another low-calorie peach nectar was prepared using high-intensity sweeteners in which the ideal sweetness concentration of sucrose was 10%. Whereas with sweeteners equivalent concentrations observed were, 0.054% for aspartame; 0.036% for cyclamate-saccharin blend (2:1), 0.10% for stevia, 0.016% for sucralose and 0.053% for acesulfame-K [67].

Mango nectar containing 7% sucrose was reported best followed by sucralose, thaumatin- sucralose blend 1:1, acesulfame-K-sucralose- neotame blend 100:50:1 and stevia [68]. In functional mango juice cyclamate-saccharin blend, aspartame, sucralose and stevia along with sucrose as control, the relative sweetness and acceptability of blend were higher than the individual sweetener. The taste profile resembled the sucrose if used in blends [69]. The blend ratio of acesulfame-K with other intense sweeteners for beverage applications may depend on the flavor or flavor type. The blends of acesulfame-K with aspartame (40:60) in orange-flavored beverages were comparable in the intensity of sweetness with sucrose-sweetened beverages [70].

Other beverages

The sweeteners including sucrose, fructose, aspartame and

saccharin were equated in tea for consumer preference, aftertaste, and cost. Sucrose was selected as least expensive and ideal sweetener than all others. Fructose and aspartame were not found to be significantly different. However, saccharin was the most disliked sweetener, and fructose was the most expensive sweetener followed by aspartame [16]. The lemon-lime and cola-flavored beverages which contained the sweeteners like sucrose, sodium saccharin, aspartame, acesulfame-K, and two calcium cyclamate-sodium saccharin blends (10:1 and 3.5:1) were assessed on the sensory scale. The drinks containing sucrose and aspartame could not be distinguished from one another in either a lemon-lime or cola. Sucrose and aspartame were also equivalent in taste for both the drinks, but acesulfame-K and sodium saccharin differed significantly from sucrose. The blends having calcium cyclamate-sodium saccharin were least preferred in beverages [71].

Instant coffee and roasted ground coffee beverages prepared using sucralose, stevia, aspartame, cyclamate-saccharin (2:1) and acesulfame-K. The sucrose concentration considered ideal by consumers in instant coffee beverages was 9.5%, with sweetener concentrations equivalent to 0.01494% for sucralose, 0.09448% for stevia, 0.05064% for aspartame, 0.04967% for acesulfame-K and 0.0339% for cyclamate-saccharin (2:1) blend. The accepted concentration was 12.5% sucrose, 0.0209% sucralose, 0.0166% stevia, 0.0724% aspartame, 0.0640% acesulfame-K and 0.0582% cyclamate-saccharin (2:1) blend in roasted ground coffee beverages [72]. Wolwer-Rieck et al. [73] evaluated the stability of two steviol glycosides, stevioside and rebaudioside A in a soft drink. They observed degradation up to 70% and found that stevioside was less stable than rebaudioside A in storage.

Sweetener	Relative sweetness*	Structure and some important properties	Blending characteristics	Taste profile	References
Acesulfame-K	100 to 200	N-sulfonyl amide structure White and non-hygroscopic crystalline Soluble in water	Qualitative and quantitative synergy with cyclamate (sodium salt) and sucralose but extensively with aspartame	Immediately sweet taste but bitter aftertaste Bitterness noticeable at high concentrations	Godshall (2007) [74] Lipinsky (1988) [75]
Aspartame.	180–200	Aspartyl-phenylalanine methyl ester White crystalline Soluble in water	Quantitative synergy with acesulfame-K and/or saccharin, cyclamate, stevia, glucose, fructose, sucrose and polyols	Similar to sucrose in taste	Godshall (2007) [74], Ripper (1985) [76]
Cyclamate	30–50	Sulfamic acid Na or Ca salt White crystalline salt Good solubility in water	Quantitative synergy with acesulfame-K aspartame, saccharin and sucralose	Slowly gives sweet but sour aftertaste at high concentrations	Godshall (2007) [74], Bakal and Nabors (1986) [77], Franta and Beck (1986) [78]
Neotame	7,000–13,000	Derivative of aspartame but more stable White powder Hydrolyzed at low or high pH	Quantitative synergy with saccharin	Intensely sweet taste with a lingering liquorice after taste	Godshall (2007) [74],

Saccharin	300-500	N-sulfonyl amide structure White crystalline Maximum solubility and stability in beverages	Quantitative synergy with aspartame, sodium cyclamate, sorbitol and mannitol	Sweet in taste but gives bitter metallic aftertaste	Godshall (2007) [74], Bartoshuk, (1979) [79]
Sucralose	600	Trichlorinated derivative of sucrose White crystalline powder Good solubility and stability in wet and dry form during processing and storage conditions	Quantitative synergy with acesulfame K, sodium cyclamate and saccharin	Intensively sweet in taste but gives metallic taste at high concentration	Godshall (2007) [74], Jenner (1989) [80], Gortz et al (2012)
Stevia	200-300	Six sweet-tasting compounds like stevioside, rebaudiosides A, D and E, dulcosides A and B White and crystalline powder Heat stable up to 198°C Non-fermentable Stable at low pH-values	-----	Slower onset of taste and longer duration than sucrose Sometimes give bitter or licorice taste at high concentrations A flavor enhancer	Pederson (1987) [81] Kobayashi et al (1977) [82]
Monk Fruit extract	150 to 300	Off white to light yellow powder Freely soluble in water	-----	Natural high potency sweetener Sweetness depends on the structure of the mogrosides i.e the number of glucose units and the food matrix	Lindley (2006) [40]

*Relative to Sucrose

Table 1: Some physico-chemical and sensory properties of artificial and natural sweeteners.

Conclusion

The growing awareness of the consumer for health and wellness has laid the greatest challenge to the beverage industry, not only of the need to deliver optimum volume growth but also to stimulate demand for the product innovation. Global beverage developments remain fundamentally complex. With the surge in diabetics and obese in many parts of the world, the number of successful light products should swell. There is no unequivocally acceptable low-calorie substitute for sucrose available to consumers. The use of increasing amounts of sugars in food formulations, sweets, and soft drinks have raised the concern about their ill effects. Therefore nowadays high intensity artificial or natural sweeteners are receiving much more attention than before, more so in the beverage world.

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