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## Trends in the Consumption of Low-Calorie Sweeteners

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### Abstract

Low-calorie sweeteners (LCS) offer a palatable alternative to caloric sugars such as sucrose (table sugar) and high fructose corn syrup and are commonly found in soft drinks, sweetener packets, grains, snack foods, dairy products, hygiene products, and medications. Consumption of LCS has increased significantly in recent years and while this trend is expected to continue, controversy exists surrounding their use. The purpose of this article is to review trends in the consumption of LCS, to summarize differences in LCS consumption across socio-demographic subgroups and subtypes of LCS-containing products, and to highlight important challenges in the accurate assessment of LCS consumption.

### Keywords

low-calorie sweeteners; artificial or non-nutritive sweeteners; diet soda; consumption trends; sweetened beverages

## 1. Introduction

Low-calorie sweeteners (LCS) are commonly-used substitutes for caloric sugars such as high-fructose corn syrup, yet their role in weight management and health remains a topic of continued controversy [1]. The purpose of this article is to review trends in the consumption of LCS in the United States (US) and worldwide and to summarize differences in LCS consumption across socio-demographic subgroups and between subtypes of LCS-containing products in the US. We also aim to highlight important challenges in the assessment of LCS consumption and to call attention to future research needs in this area.

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## 2. Low-calorie sweetener definitions and history

LCS are a class of highly sweet compounds which contribute no or few calories [2]. As such, they are commonly used in foods and beverages to lower calorie content while maintaining palatability [3]. LCS are also referred to as artificial sweeteners, nonnutritive sweeteners, high-intensity sweeteners, and non-caloric sweeteners. There are six LCS approved for use as food additives by the US Food and Drug Administration (FDA) [2]. These include acesulfame-potassium, aspartame, advantame, neotame, saccharin, and sucralose. In addition, stevioside and rebaudioside A (both sweet extracts of the *S. Rebaudiana* Bertoni plant) as well as *luo han guo* (monkfruit) are considered generally recognized as safe (GRAS), meaning that expert consensus has been reached in order to determine that the food additive is safe for its intended use [4]. The GRAS process differs from that of food additive approval, as safety data for food additives, are submitted to the FDA for review to determine whether the substance is safe, prior to arriving on the market [4]. Other LCS, including alitame and cyclamates, are not approved for use in the US but are approved and commonly used in many other parts of the world [5]. Sugar alcohols and other sugar substitutes, such as high fructose corn syrup are not included in this review, as they contain calories and are therefore not LCS.

The first LCS, saccharin, was discovered by accident in the late 1800's [6]. Initially, saccharin was exclusively used as a medicinal product for individuals with diabetes and did not reach the general population until World War II, when sugar shortages prompted consumers to turn to LCS for sweetness [6]. Cyclamate was the second LCS to be discovered in 1937, but was banned in the US in 1969 due to concern about carcinogenicity [7]. Despite the discoveries of saccharin and cyclamate during the late 19<sup>th</sup> and early 20<sup>th</sup> centuries, LCS use was not common in the general population until the discoveries of newer LCS, including aspartame, acesulfame-potassium, and sucralose [8], approved in 1981, 1988, and 1999, respectively.

The approval of these newer LCS, in combination with a simultaneous rise in diet programs and a concomitant increase in marketing of LCS and LCS-containing products, led to a dramatic increase in their availability and consumption [9]. LCS currently comprise a significant portion of the total sucrose substitute market share (which also includes high fructose corn syrup and low-intensity sweeteners such as sugar alcohols [7]) and the LCS market is expected to continue to experience growth [10]. Reasons for this growth include increasing concerns surrounding health and nutrition, the ability to blend several LCS to enhance palatability, and the lower cost of LCS relative to sucrose [7]. As a whole, the LCS market has seen considerable growth since 2002, primarily due to significant expansion in sucralose availability following its approval as a general purpose sweetener in 1999, in part due to its high stability in food [7].

## 3. Low-calorie sweeteners in foods, beverages, and other applications

While their use was once limited primarily to tabletop packets and diet soft drinks, LCS are now found in grain products including breads, cereals, and granola bars, dairy products including sugar-free or "lite" yogurts, no-sugar added ice cream, and flavored milk. In

addition to reduced-calorie grains, dairy products, and desserts, LCS are also added to a wide range of condiments including reduced-sugar ketchup, sugar-free jam, and sugar-free pancake syrup and are found in medications, multivitamins, and hygiene products (e.g. flavored toothpaste and mouthwash). While only 1.5% of the over 85,000 unique food and beverage products available in the United States from 2005-2009 contained LCS, 15% of the volume of foods and beverages purchased contained LCS [11]. Despite the relatively few LCS-containing products compared to those sweetened with caloric sugars, LCS represent a significant portion of the market in specific product categories, such as flavored waters (42%) and yogurts (33%), in addition to diet beverages [11].

Beverages and specifically diet carbonated beverages comprise the largest proportion of LCS consumption worldwide, followed by tabletop sweeteners and LCS-containing foods [12]. In the US specifically, LCS-containing beverages comprise 19% and 32% of all beverages purchases by volume among children and adults, respectively [13]. As the demand for reduced-calorie and lower-sugar products continues to increase, growth in sales of LCS-containing food and beverage products is projected across various LCS-containing product categories. For example, projected annual growth rates were 3.4%, 4.9%, 3.8%, and 3.2%, for reduced-sugar beverages, confectionary, bakery products, and ice cream, respectively, from 2012-2015 [7]. Thus, the availability of LCS in the food supply will likely increase [11].

#### 4. Global trends in the sales of low-calorie sweeteners

Cyclamate and saccharin are the least expensive LCS and comprise the majority of LCS consumption worldwide [12]. Because cyclamate is only 30 times sweeter than sucrose by weight, compared to approximately 200 times, 300 times, 600 times for aspartame and acesulfame-potassium, saccharin, and sucralose, respectively [3], cyclamate leads the LCS market only when consumption is calculated by volume [12]. In addition, as mentioned above, cyclamate is not FDA approved. In contrast, saccharin is the worldwide market leader based on sucrose equivalents and has a particularly strong presence in the tabletop packet market, primarily as Sweet 'N' Low™ [7].

Demand for reduced-calorie foods is particularly high in North America [10]. In 2009, consumption of LCS in the US was responsible for 15% and 26% of the total global LCS consumption by volume and sucrose equivalence, respectively [7]. However, in contrast to other parts of the world, sucralose accounts for the majority of the LCS market share in the US, having recently surpassed aspartame [14]. It is expected that sucralose will continue to gain market share with corresponding reductions in aspartame sales [7]. For example, sucralose recently replaced aspartame in the wide consumed soft drink, Diet Pepsi™, which is now marketed by PepsiCo as “now aspartame free.”

Worldwide, the LCS market is expected to reach \$2.2 billion by 2020, with its annual growth at approximately 5.1% per year from 2008-2015 [15], and with the greatest growth expected in Latin America and in China [7]. As consumer preferences continue to shift toward natural products, the global consumption of stevioside and rebaudioside A, is expected to increase more rapidly than other LCS [12]. In addition to its appeal as a natural LCS, rebaudioside A

is also perceived as being more palatable than other LCS [7] and food and beverage manufacturers are therefore expected to expand the incorporation of stevioside and rebaudioside A in newly formulated products [7].

## 5. Population trends in the consumption of low-calorie sweeteners in the United States

Though LCS are consumed worldwide, reliable national level estimates of trends in population prevalence of LCS consumption are limited to data from the US [16-19]. Four recent studies have reported estimates of LCS consumption in the US [13, 16-18]. While estimates are consistent across studies, consumption is likely under-estimated due to the inherent limitations of reliably evaluating LCS consumption, detailed in Section 7. Using 24-hour dietary recall data from the National Health and Nutrition Examination Survey (NHANES), consumption of LCS increased from approximately 26.9% in 1999-2000 to 32.0% in 2007-2008 among adults in the US and from 8.7% in 1999-2000 to 15.0% in 2007-2008 among children [16]. Similar estimates were reported in another study using NHANES data from 2003-2010, with the percentage of the population reporting consumption of LCS-containing beverages increasing from 21.1% in 2003-2004 to 24.9% in 2009-2010 among adults and from 7.8% to 18.9% among children over this same time period [13].

In both children and adults, the consumption of LCS beverages increased, primarily due to increased consumption of reduced-calorie beverages (e.g. light fruit drinks, reduced-calorie sport drinks). Meanwhile, consumption of no-calorie beverages (e.g. diet soda) remained relatively stable [16], and few differences were observed in consumption of LCS foods. Consumption of LCS-containing foods is reported to have remained quite low [5, 13, 16].

Data from the Nielsen Homescan (The Nielsen Co., [www.nielsen.com](http://www.nielsen.com)) have also been used to evaluate household purchases of food and beverage products with LCS, as a proxy for estimating individual consumption [11, 13]. Increases in the percentage of households purchasing LCS-containing beverages were reported from 2000-2010 and per capita volume of LCS-containing beverages also increased over this time period. Similar to our report using NHANES data [16], consistent increases were observed in purchases of low-calorie beverages containing LCS (e.g. light fruit drinks containing both caloric sweeteners and LCS), while purchases of no-calorie beverages (containing only LCS but not caloric sugars) increased between 2000-2006 and then declined from 2006-2010 [13]. Trends in household LCS-containing food purchases were similar to trends in LCS-containing beverages using NHANES. However, the magnitude of the changes was smaller using food purchase data when compared to NHANES, likely due to the different methods used [13].

Most recently, according to NHANES data from 2009-2010, approximately 20% of Americans 2 years of age reported consumption of beverages with LCS on a given day [18]. Another report evaluating LCS consumption using NHANES data from 1999-2008 reported that approximately 30% of US adults consumed LCS daily [17]. When separated by source of LCS, 19.5% of adults reported consuming beverages with LCS, while 11.4% and 4.6% of adults reported consuming tabletop packets and foods with LCS, respectively [18].

Thus, beverages with LCS continue to comprise the majority of reported LCS consumption. In addition to estimates of daily LCS consumption, a report published in 2007 by the Calorie Control Council, an international association representing the low- and reduced-calorie food and beverage industry, documented that 85% of the US population self-reported ever using LCS, during a consumer survey [20]. This however does not account for individuals who are not aware of ever being exposed to LCS. For example, infants of mothers who consume LCS containing products ingest LCS through their mother's breast milk [21].

While patterns in LCS containing beverage consumption have been studied in other countries including in Canada [22], Brazil [23], Denmark [24], and South Korea [25], only the average volume of LCS containing beverages consumed or the average intake by body weight is reported, while the percentage of the population consuming LCS beverages is not available.

## 6. Population trends in the consumption of low-calorie sweeteners globally

While only limited data is available, existing studies suggest that LCS consumption is common worldwide. According to estimates from a representative sample of the German population in 1988, approximately 36% of participants reported consuming LCS [19], which is similar to estimates reported in the United States [16]. Current consumption in Germany is likely higher than what was reported above, as this estimate was generated prior to the approval of aspartame as a general purpose sweetener and before newer LCS including acesulfame-potassium and sucralose became available. Though also not designed to evaluate temporal trends in LCS consumption, recent data from Western Australia estimate that 37.4% of the general adult population (age 16 years and older) consume diet soft drinks on a weekly basis [26] and is also consistent with U.S. data [16].

Particularly high LCS consumption has been reported in Central and South America [27, 28]. A recent study in Latin American college students reported that 80% of those surveyed reported weekly consumption of LCS, with the highest consumption reported among students in Chile [27]. Among 10-16 year old students in two Chilean cities, 96.6% reported daily LCS consumption [28]. In contrast, consumption of low-calorie (LCS-containing) drinks was reported to be only 8.3% among both children and adults in Mexico between 1999-2010 using dietary recall data from the Mexican Nutrition Survey 1999 (n = 6049) and the National Health and Nutrition Survey 2012 (n = 10,343) [29]. Reasons underlying these discrepant findings have yet to be elucidated.

### 6.1. Characteristics of LCS consumers

In both children and adults, increases in consumption of low-calorie beverages with LCS were observed regardless of socio-economic status and were more dramatic among females compared to males [16]. Furthermore, increases in low-calorie beverage consumption were observed among all weight status subgroups (normal weight, overweight, and obese) in adults, but only among normal weight children [16]. Consumption trends by race/ethnicity also differed among children and adults, with the most pronounced increases observed among non-Hispanic Black children [16] but with no increases observed among non-Hispanic Black adults. Meanwhile, LCS consumption did increase among non-Hispanic

White and Hispanic adults. Trends in LCS consumption also differed based on age, with the most notable increases in consumption observed among 6-11 year old children and among older adults (>55 years of age), compared to other age-groups.

### 6.1. Socio-demographic differences in current HIS consumption

While the sociodemographic differences discussed thus far refer to differences in consumption trends over time, current prevalence of LCS consumption differs by age, race/ethnicity, body weight, and socio-economic status. Consumption of LCS increases with age [17, 18] and is most common among adults between 55 and 74 years of age compared to younger individuals. Increasing consumption with increased age was also observed using household purchase data [13]. Consumption of LCS also varies by weight status, with the highest prevalence of consumption reported by overweight and obese adults, compared to their normal weight counterparts [16]. LCS consumption is particularly high among successful maintainers of weight loss [30]. Using data from the National Weight Control Registry, approximately 66% of individuals who had successfully maintained weight loss for >1 year reported consuming a LCS-containing beverage weekly, with reported consumption of various LCS beverages including diet soft drinks, coffee/tea with LCS, and LCS containing juices and sports drinks substantially higher in this cohort than in the general adult population [18, 30]. Comparing LCS consumption by race/ethnicity, non-Hispanic White Americans having higher prevalence of LCS consumption compared to non-Hispanic Black Americans, LCSpanic Americans, and other race/ethnicity groups [13, 16, 17], though consumption among minorities has increased, as discussed for temporal trends in consumption in Section 5.1 above. LCS consumption is also positively associated with socio-economic status and educational attainment, with higher income families reporting the highest prevalence of LCS use [17]. These socio-demographic differences were consistent when evaluating LCS consumption using household purchase data [13].

Interestingly, while prior studies using data from NHANES 1999-2008 have reported higher LCS consumption among females compared to males [16, 17], but more recent data (NHANES 2009-10) show similar consumption among both genders. The only exception are female adolescents 12-19 years of age who consumed more LCS than their male counterparts [18].

## 7. Considerations in the analysis and interpretation of LCS consumption data

In addition to general limitations affecting the precision and reliability of dietary assessments, such as the use of self-report methods [31], there are several additional shortcomings inherent in the assessment of LCS consumption. While producers and manufacturers are required to list LCS on product ingredients lists, the FDA does not require disclosure about the quantities of LCS in a given product with the exception of saccharin. Therefore, the available information precludes exact assessment of LCS intake, though LCS intake can be assessed indirectly through analysis of household sales data [5, 13].



Furthermore, the presence and description of specific types of LCS are frequently absent from nutrient databases. Products that contain LCS may therefore be overlooked in dietary surveillance. For example, the USDA Food and Nutrient Database for Dietary Studies (FNDDS) [32] and the USDA National Nutrient Database for Standard Reference [33] list many food and beverage items as either containing a “low-calorie sweetener,” “dietetic,” or “sugar-free,” yet information about the specific LCS is not readily accessible. In addition, while many food codes in FNDDS are listed as “sugar-free,” “diet,” or “with low-calorie sweetener,” LCS are also included in foods and beverages with other food code descriptions that do not clearly indicate the presence of LCS.

The oversight of LCS-containing products is particularly relevant for food codes where only a select subset or brand of products with a certain food code contains LCS. For example, the widespread presence of sucralose in a commonly consumed brand of whole wheat (e.g. not light or diet) English muffins is likely to be overlooked because some but not all whole wheat English muffins contain LCS. Furthermore, products marketed for content of other nutrients, for example, high fiber, may also contain LCS [34]; however, their presence is not reflected in the corresponding food code description. Finally, new LCS-containing products are rapidly being introduced, while the composition and formulation of existing LCS-containing products are constantly changing [13]. This makes accounting for products that contain LCS and capturing the specific LCS in foods and beverages in nutrient databases increasingly difficult and challenges the reliability of current consumption estimates.

Piernas et al. [13] used household purchase data (Nielsen Homescan) linked to frequently updated and comprehensive ingredient list and nutrition facts panel information (Gladson Nutrition Database). This approach overcomes several of the above described limitations, but does not provide a direct measure of intake. In addition, while the use of these often difficult to access data sources provides access to sweetener- and product-specific information, the proprietary nature of food label information still limits the availability up-to-date, accurate and comprehensive food composition data.

## 8. Conclusions

Consumption of LCS has increased and will continue to increase in the US and worldwide. Sucralose has become the most commonly used LCS, while other sweeteners (e.g. aspartame) are becoming less popular. Concurrently, popularity of newer and natural sweeteners, namely stevia, is increasing. Consumption of LCS varies according to age, race/ethnicity and socio-demographic factors with white, older, and more educated consumers leading the charts. Our review calls attention to the need to expand existing knowledge of the metabolic and health effects of LCS, particularly when consumed chronically over weeks, months, or years. Improvements in dietary assessment methodologies and modifications to food labeling regulations are also required to increase the accuracy of LCS consumption estimates and to encourage reliable dietary surveillance.

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**Highlights**

- Low-calorie sweeteners (LCS) are found in foods, beverages, packets, and hygiene products.
- Consumption of LCS is common in the US population and has increased significantly over the past decade.
- LCS consumption differs across socio-demographic and weight status subgroups.
- Several barriers prevent accurate and reliable quantification of LCS consumption.