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Consumption of low-calorie sweeteners: findings from the Campinas Nutrition and Health Survey

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Abstract

We used data from the Campinas Health Survey (ISACamp 2014/15) and the Food Consumption and Nutritional Status Survey (ISACamp-Nutri 2015/16) to estimate the prevalence of the consumption of foods and beverages that contain low-calorie sweeteners (LCS) by individuals ≥ 10 years to estimate the dietary exposure of the population to high levels of LCS. We first estimated the prevalence of consuming LCS-containing foods and beverages and identified the top sources of LCS consumption. We then verified whether the prevalence of consumption varied according to individual-level characteristics or the presence of obesity and diabetes. Finally, we estimated the population dietary exposure to high levels of LCS and compared it with the acceptable daily intake (ADI) levels. Over 40 % of the study population consumed at least one LCS-containing food or beverage. Sweetened beverages, tabletop sweeteners and dairy beverages were the top contributors to the consumption of LCS. Among all age groups, education levels, and income levels, the consumption of LCS-containing foods and beverages ranged from 35 % to 55 %. The prevalence was only slightly greater among higher income 40–59-year-olds than among other income groups and was not higher among individuals with obesity or diabetes. Although dietary exposure to LCS did not exceed the ADI levels, we identified several limitations in our ability to measure exposure to high levels of LCS. Because of these challenges and the unclear evidence linking LCS to better health outcomes, the consumption of LCS-containing foods and beverages should be closely monitored.

Key words: **Sweeteners: Food intake: Food additives: Population-based: Brazil**

Several products have been used over the years to sweeten foods, such as honey[1] and sugar[2]. Over the past decades, synthetic substances and low-calorie alternatives with the primary function of replacing sugar to provide sweetness to foods have been developed[3]. Various terms are used in the literature for such substances, but 'low-calorie sweeteners' (LCS) covers most of the different types of these substances that are used throughout the world, including artificial non-nutritive sweeteners, natural non-nutritive sweeteners and sugar alcohols[4]. Despite the term 'natural', natural non-nutritive sweeteners are synthetic compounds that are obtained through industrial processes[3].

LCS were originally recommended for people with conditions related to excessive sugar intake, such as diabetes[5]. They quickly became popular with consumers seeking to control their body weight[6]. LCS are now found in several ultra-processed foods and beverages that are consumed by the broader population, including children and adolescents[7–10]. In Brazil, LCS are found in approximately 10·0 % of all packaged foods and beverages and in 14·6 % of ultra-processed foods and beverages[11,12]. They can also be found in products with front-of-package child-directed advertising and, many times, without any front-of-package information[12]. The presence of LCS in Mexico and Chile shows rates similar to or greater than those in Brazil, yet apparently lower than what has been reported for high-income countries[10].

The consumption of LCS-containing foods and beverages has increased over the last decades in many countries[13]. Recent national estimates from Brazil also show that 8·5 % of the population report using tabletop sweeteners[14]. Although

Abbreviations: ADI, acceptable daily intake; LCS, low-calorie sweeteners.

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older adults and individuals with a higher Body Mass Index (BMI) or diabetes are more likely to consume LCS[15–17], a growing body of evidence has shown that LCS can have a contradictory effect on weight loss and glucose control[18,19]. In fact, saccharin and aspartame appear to be associated with increased gut production of bacteria associated with weight gain, and sucralose and saccharin might lead to inflammation and compromise the insulin response to sugar intake[20]. Similarly, beverages sweetened with LCS are not necessarily healthier alternatives to sugary drinks for the prevention of type 2 diabetes[21] or gestational diabetes[22]. A population-based cohort study in France showed that aspartame and acesulfame were associated with increased cancer risk[23].

Children and adolescents constitute a risk group because they have a higher intake of foods and beverages per kilogram body weight, because the consumption of products sweetened with LCS during childhood can modulate dietary preferences throughout life and contribute to overweight and obesity[24], and because of the uncertainty about the long-term effects of LCS consumption[25]. In addition, children who consume beverages with LCS can compensate for the diluted energy content by eating more solid food calories[26].

In Brazil, a recently approved front-of-package nutritional label with a magnifying glass that identifies foods and beverages with high contents of total sugars, sodium and saturated fat can contribute to healthier food choices[27], but it might lead to an increased prevalence of LCS-containing foods and beverages as a response by the food industry to replace sugar with LCS[28,29]. In Chile, regulatory policies that target foods with a high content of total sugars and sugar-sweetened beverages led to an increase in LCS use from 37·9 % to 43·6 % after the initial implementation of the labelling law[29].

Evidence on the population intake levels of LCS is limited in Brazil and is even scarcer for children and adolescents[30]. Considering the limited evidence on the consumption of LCS-containing foods and beverages in Brazil and the forthcoming incentives for the food industry to partially or fully replace added sugars in foods and beverages with LCS[31], we estimated the consumption of these products among individuals aged 10 years and older. We did this by using detailed data on the consumption of LCS-containing foods and beverages obtained from a population-based survey conducted in a large city in Brazil. We also identified the top sources of LCS consumption and verified whether the prevalence ratios of the consumption of LCS-containing foods and beverages were greater among individuals with obesity and diabetes, which are conditions known to be associated with higher LCS consumption. Additionally, we estimated the dietary exposure of the studied population to high levels of LCS using acceptable daily intake (ADI) levels.

Methods

Study design and population

This cross-sectional study included information from 2570 individuals aged ≥ 10 years obtained through by the population-based surveys 'Campinas Health Survey (ISACamp) 2014/15' and 'Food Intake and Nutritional Status Survey (ISACamp-Nutri 2015/16)', which were carried out in Campinas, Brazil. Located in the State of Sao Paulo, Campinas is the largest city of the Metropolitan Area of Campinas and had an estimated population of 1 213 792 inhabitants in 2020[32]. It is richer than most cities in Brazil, with a domestic gross product above the country's average; however, there is high social inequality, and 9·83 % of the population lives below the poverty line[32].

ISACamp 2014/15 had a two-stage, stratified, probabilistic, cluster sampling method. In the first stage, seventy census sectors were drawn with probabilities proportional to their size, which was indicated by the number of households. The census sectors were organised by the mean income of the heads of the household, and fourteen sectors were selected from each of the five health districts in the municipality. The number of participants was determined by considering a 50 % proportion to ensure maximum variability, a sampling error of 4 to 5 % points, and a design effect of 2. More detailed information on the sampling process can be found elsewhere[33].

The survey included information on co-morbidities, use of health services, preventive practices, health-related behaviours, use of medications, demographic information and socio-economic characteristics. The data collection was performed by trained interviewers using a tablet. The participants signed an informed consent form, and the study was approved by the Institutional Review Board Committee of the University of Campinas and the Brazil National Committee for Ethics in Research.

Dietary intake assessment

As part of the ISACamp 2014/15, trained interviewers used a tablet to conduct a 24-h food recall using the multiple-pass method, a technique that aims to stimulate the respondent's memory and increase the accuracy of the information[34], with the support of a photographic manual.

The reported foods, beverages and preparations were recorded in units and home-made measurements; they were then quantified in grams or millilitres and imputed into NDS-R software, version 2015 (Nutrition Coordinating Center, University of Minnesota). The data were entered twice and then checked for consistency.

Identification of low-calorie sweeteners in foods and beverages

Estimating the consumption of LCS-containing foods and beverages poses two challenges that can lead to uncertainties: (i) identifying the concentration of LCS in foods and beverages (the amount of each LCS type added to the foods and beverages) in the absence of such information on the food label, and (ii) reliably measuring the consumption of LCS-containing foods and beverages[35]. We took the following actions to address these challenges.

The nutritional composition table of the software we used to enter food intake data (NDS-R software) was provided by the US Department of Agriculture[36] and therefore listed foods sold in the USA. Thus, we attempted to replace the nutrition composition of the packaged foods and beverages reported in the 24-h

food recall with information from the Brazilian Food Label Database[37], which is a database of over 11 000 packaged foods and beverages collected in 2017. Nutrition information was gathered from the packaging of foods and beverages sold in the five largest food retailers in Brazil[37]. We considered a food or beverage to contain LCS if one of the following substances that are approved as a food additive by the Brazilian Agency for Sanitary Surveillance (ANVISA) was in the ingredients list: artificial non-nutritive sweeteners (acesulfame potassium, aspartame, neotame, saccharin, sucralose and sodium cyclamate); natural non-nutritive sweeteners (steviol glycosides and thaumatin); and sugar alcohols (erythritol, isomalt, lactitol, maltitol, mannitol, sorbitol and xylitol)[38].

To address the uncertainty in the estimates of the consumption of LCS-containing foods and beverages LCS, we proposed three possible scenarios of LCS consumption following the methodology developed by Duarte *et al.* (2022)[39].

In scenario 1, foods and beverages were considered to contain LCS if brand and flavour information were available on the 24-h food recall and LCS were confirmed to be in the list of ingredients according to the Brazilian Food Label Database[12,37]. For packaged foods or beverages for which the brand was reported in the 24-h food recall but was not available in the Brazilian Food Label Database, we searched the ingredient list for that product on the food company webpage to verify whether the product contained LCS. In this scenario, we also included all reported tabletop sweeteners.

In scenario 2, in addition to the foods and beverages included in scenario 1, we added foods and beverages that did not have brand and flavour information available in the 24-h food recall but that were likely to contain LCS, such foods and beverages were reported to be 'diet', 'light', 'zero', 'with no added sugar(s)' or 'with sweeteners'. Because all fruit-flavoured drink mixes that were available for sale in the top Brazilian supermarket chains were sweetened with LCS[12], we included all fruit-flavoured drink mixes in scenario 2.

To construct scenario 3, we first gathered information on the market share of several brands of foods and beverages sold in Brazil in 2016 organised by Kantar-IBOPE[40]. We then replaced the foods and beverages for which brand and flavour information had not been reported in the 24-h food recall with the top selling brand/flavour in each food and beverage category. We included those foods and beverages with at least one type of LCS in the ingredients list according to the Brazilian Food Label Database[12,37]; these foods and beverages were included along with those identified in scenarios 1 and 2 to form scenario 3.

Scenario 1 was considered the least conservative, and scenario 3 was the most conservative. When dealing with uncertain food intake estimates, it is important to prevent the underestimation of risk[41].

Estimates of the population dietary exposure to high levels of low-calorie sweeteners

Brazilian legislation does not mandate food companies to state the quantity of LCS on the labels of foods and beverages that are not considered to be for a special purpose, that is, foods and beverages not designated as 'diet' or 'light'[42]. Therefore, to estimate the population dietary exposure to high levels of LCS, for each LCS, we applied the maximum limit of the LCS established by Brazilian legislation per 100 grams or millilitre of the product[38].

The maximum amount of LCS allowed by Brazilian legislation depends on whether the product has partial or total sugar replacement[38]. Foods and beverages were considered to contain LCS for the partial replacement of sugars if they had added sugars in their composition, and for the total replacement of sugars if there were no added sugars. Information on added sugars was obtained from the Brazilian Food Labels Database, which identified the following substances as added sugars: sugar, honey, syrups, molasses, maltodextrin, glucose, fructose, concentrated fruit and vegetable juices, and sweets such as chocolate and sweetened milk[12,37].

As the ADI information for steviol refers to steviol glycosides, we converted the steviol equivalents found in foods and beverages considering a 50 % mixture of stevioside (conversion factor = 0·4) and rebaudioside A (conversion factor = 0·3)[39,43].

We estimated the quantity of LCS in tabletop sweeteners using the values determined by Noronha when assessing the amount of LCS found in tabletop sweeteners sold in Brazil[44]. Because the concentration of neotame was not determined in the study[44], we used the mean value of the other LCS evaluated. We were also unable to quantify the number of drops of liquid tabletop sweeteners and the amount of powdered sweeteners participants added to the reported foods and beverages and we used previous estimates reported for Brazil[45,46]. These were: for liquid tabletop sweeteners, we considered an average of six drops for each reported use (equivalent to 0·27 g of LCS), and for tabletoppowered sweetener, we considered one sachet (equivalent to 0·8 grams of LCS) per 200 millilitres of beverage.

Food categories

LCS-containing foods and beverages were classified into the following categories[12,37]: bakery products, candies and desserts, breakfast cereals and granola bars, condiments and salad dressings, dairy beverages, sweetened beverages, and tabletop sweeteners (Supplementary file 1).

Individual-level characteristics

We estimated the prevalence of the consumption of LCS-containing foods and beverages by age (10–19, 20–39, 40–59 and over 60 years old), sex, race/ethnicity (White and non-White, which included participants who self-reported as Black, Brown, Asian or Indigenous), per capita household income minimum wage (< 1, 1–3, 3 or more), and educational level of adults over 19 years old and the main child/adolescent caregiver's educational level (< 8, 8–11, 12 or more years). Minimum wage referred to the minimum wage established in 2015 (BRL 788·00)[47]. We also estimated the prevalence of the consumption of LCS-containing foods and beverages as the presence of directly measured obesity (BMI ≥ 30 kg/m^2)[48] or self-reported diabetes among participants ≥ 20 years old or older.

Statistical analyses

We first estimated the overall prevalence of the consumption of LCS-containing foods and beverages in the population-based sample using the three proposed scenarios. Using the most conservative consumption scenario (scenario 3) to not underestimate the consumption, we determined the top sources of LCS consumption and estimated the adjusted prevalence ratios of consumption after ajusting for individual-level characteristics using Poisson's regression models stratified by age. The Poisson distribution was chosen because of the relatively high prevalence of the outcome variable, because logit models are likely to overestimate OR when working with frequent outcomes. We verified whether the prevalence of the consumption of LCS-containing foods and beverages differed by age, sex, race/ethnicity, income, and education level and whether the prevalence of such consumption was greater among participants ≥ 20 years with directly measured obesity (BMI ≥ 30 kg/m^2)[48] or self-reported diabetes.

Finally, we estimated the mean, median and 95th percentile of LCS consumption to verify whether the studied population dietary intake exceeded the ADI levels for each one of the assessed LCS expressed in milligrams per kilogram of body weight per d (mg/kg/d) using Equations 1 and 2[38].

LCS-containing foods and beverages:

$$\frac{\sum(\textit{LCS limit value per } 100\ g \textit{ of food } (g) \times \textit{consumed amount of food } (g)/100)}{\textit{individual body weight } (kg)} \quad (1)$$

Tabletop sweeteners:

$$\frac{\sum(\textit{LCS content determined for tabletop sweeteners per } 100\ g \textit{ of product } (g) \times \textit{consumed amount of product } (g)/100)}{\textit{individual body weight } (kg)} \quad (2)$$

We used the svy command to account for the multistage complex sampling in all analyses conducted in Stata/MP 16·1 (StataCorp LLC).

Ethics approval

This study received approval from the Human Research Ethics Committee of the University of Campinas (certificate no. 22425019·3·0000·5404) and the National Ethics Committee (CEP/CONEP system) (42779220·9·0000·5404). All participants signed an informed consent form before being interviewed.

Results

Figure 1 shows the three proposed LCS consumption scenarios. The prevalence of consuming LCS-containing foods and beverages LCS was 17·1 % (95 % CI 14·7, 19·7) in scenario 1, 36·8 % (95 % CI 33·8, 39·8) in scenario 2 and 44·5 % (95 % CI 41·2, 47·7) in scenario 3. The age-stratified analyses of LCS consumption using the three scenarios showed similar results (Supplementary file 2). Stratified estimates are reported for scenario 3 only; this was the most conservative scenario and thus is the least likely to underestimate the consumption.

Artificial non-nutritive sweeteners were the most consumed type of LCS in this population, followed by sugar alcohols and natural non-nutritive sweeteners. Notably, many of the reported foods and beverages had a combination of two or more types of LCS (Supplementary 3).

Figure 2 shows that LCS were found in seven food categories. The top sources of LCS consumption among all participants were sweetened beverages, tabletop sweeteners and dairy beverages. While tabletop sweeteners were the top source of LCS for those aged 40 years or older, sweetened beverages were the top source of LCS for adolescents.

For all age groups, 35·0 % to 55·0 % of individuals consumed LCS-containing foods and beverages (Supplementary file 2). Forty per cent of adolescents reported consuming at least one food or beverage containing LCS, and estimates were similar across all sex, age, race/ethnicity and socio-economic strata (Table 1).

Among participants aged 20 years or older, estimates were similar across all strata, except there was a higher prevalence among 40–59-year-olds with some college (prevalence ratio = 1·4; 95 % CI 1·1, 1·8) compared with those with less than 8 years of education (Table 1). The prevalence of consuming LCS-containing foods and beverages was not higher among those with obesity or diabetes (Fig. 3).

The population dietary exposures to LCS did not exceed the ADI thresholds for each LCS (Supplementary file 4).

Discussion

We used three different scenarios – from least to most conservative – to estimate the prevalence of consuming LCS-containing foods and beverages in a population of individuals aged 10 years or older from a large Brazilian city. We found that between 17·1 % and 44·5 % of the participants reported consuming at least one food or beverage that contained an LCS. Because the most conservative scenario was least likely to underestimate the prevalence of consuming LCS-containing foods and beverages, we opted to report a 44·5 % consumption. In this conservative scenario, 44·47 % of adolescents, 43·38 % of adults aged 20 to 39 years, 46·02 % of adults aged 40 to 59 years and 45·67 % of adults older than 60 years consumed at least one LCS-containing food or beverage on the reported day. Using the conservative approach, the prevalence of consuming LCS-containing foods and beverages in our study was higher than in reports from other countries, such as Australia (18·0 %)[16], the USA (30·0 %)[49] and Germany (36·0 %)[50], but it was lower than estimates reported for Central and South American countries[51,52]. The prevalence in younger people of consuming products sweetened with LCS was as high as that found in previous studies. For instance, approximately 80 % of Latin American college students from Chile, Panama, Guatemala and Peru reported weekly consumption of beverages containing LCS[52].

Data on the prevalence of consuming LCS-containing foods and beverages are available for only select countries; however,

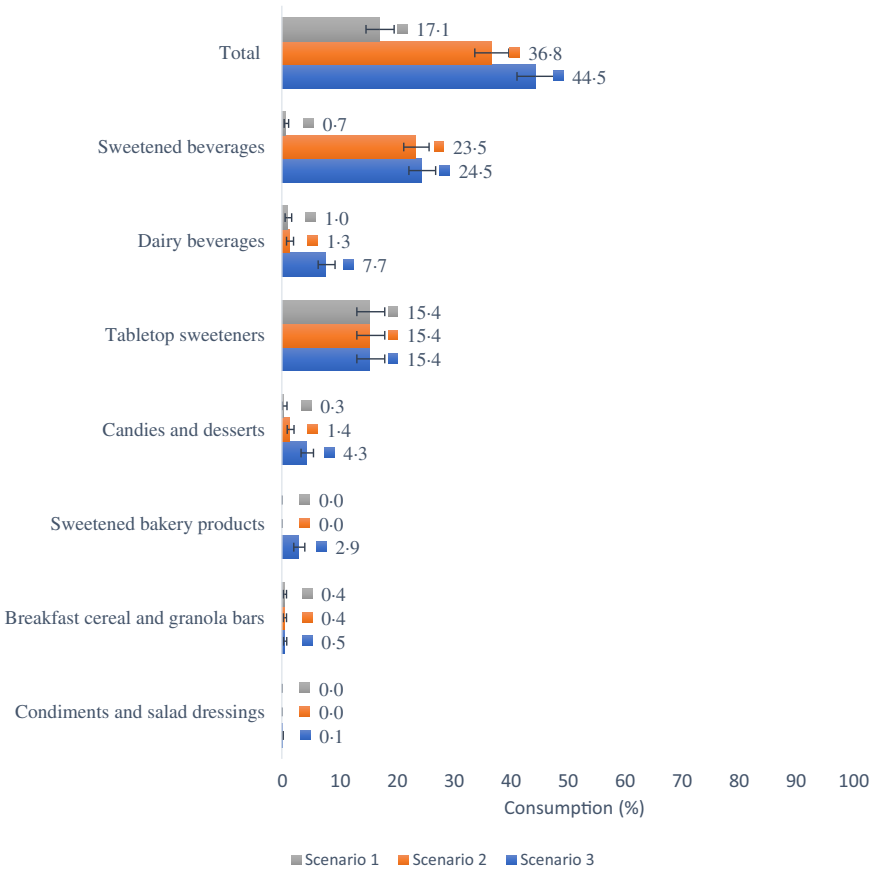

Fig. 1. Consumption of foods and beverages containing low-calorie sweeteners using three different estimation scenarios. Campinas, SP, 2015/16. LCS, low-calorie sweetener. Scenario 1: LCS-containing foods and beverages identified by brand in the 24-h food recall + tabletop sweeteners; scenario 2: scenario 1 + foods and beverages likely to contain LCS (diet, light, and reduced sugars) + fruit-flavored drink mixes; scenario 3: scenario 1 + scenario 2 + top selling brand/flavor of LCS-containing foods and beverages.

the consumption seems to be frequent where information is available[13,53,54]. As the consumption of ultra-processed food increases[55,56], the dietary exposure to LCS also increases because a variety of food additives (including LCS) are added to these foods. Despite their being marketed as health substitutes for sugar, the adverse effects associated with the frequent use of LCS are becoming a public health concern[57]. In fact, the available evidence is inconclusive as to whether LCS help to control elevated blood glucose levels[58] and weight gain among adults[20]. Recent evidence has suggested that the regular consumption of LCS-containing foods and beverages may be associated with increased BMI and cardiometabolic risk[59], alterations of the gut microbiota composition[60] and increased cancer risk[23]. Among children and adolescents, the consumption of LCS-containing foods and beverages has been associated with higher energy intake[61] and increased BMI[62].

When LCS were initially developed, they were mostly consumed by people with diabetes[5]. Today, LCS are used in a wide range of foods and beverages[8,12,63,64], comprising a sizeable share of the market of sweetened beverages, yogurts and flavoured waters[64]. We identified two different profiles of the consumption of LCS-containing foods and beverages. Among adolescents and younger adults, sweetened beverages were the top source of LCS dietary intake; for those older than 40 years, tabletop sweeteners were the top source of LCS, corroborating previous findings from a population-based sample in Brazil (Pelotas, Rio Grande do Sul)[45]. Unsurprisingly, 70 % of sweetened non-dairy beverages and 27 % of dairy beverages sold in Brazil's top five largest retailers contain LCS[12]. Soft drinks, yogurts and tabletop sweeteners are also the main dietary sources of LCS in Australia and the USA[16,65].

Artificial non-nutritive sweeteners were the most-consumed LCS in all age groups. Indeed, sucralose and acesulfame potassium are two of the most frequently added LCS to foods and beverages sold in Brazil[11,12]. Cyclamate and saccharin, two other artificial non-nutritive sweeteners, are the least expensive LCS allowed in foods and beverages and are, correspondingly, the most highly consumed LCS worldwide[66].

The consumption of LCS-containing foods and beverages in our sample did not differ across most of the age, sex, race/ethnicity and socio-economic strata. Nor was the prevalence different among adults with obesity or a self-reported diagnosis of diabetes compared with individuals without these health conditions. However, previous estimates in Brazil, USA and Australia have found that women and higher income individuals are more likely to consume LCS-containing foods and beverages, as are those with obesity or diabetes[6,7,16,49]. We observed differences in the prevalence of consuming

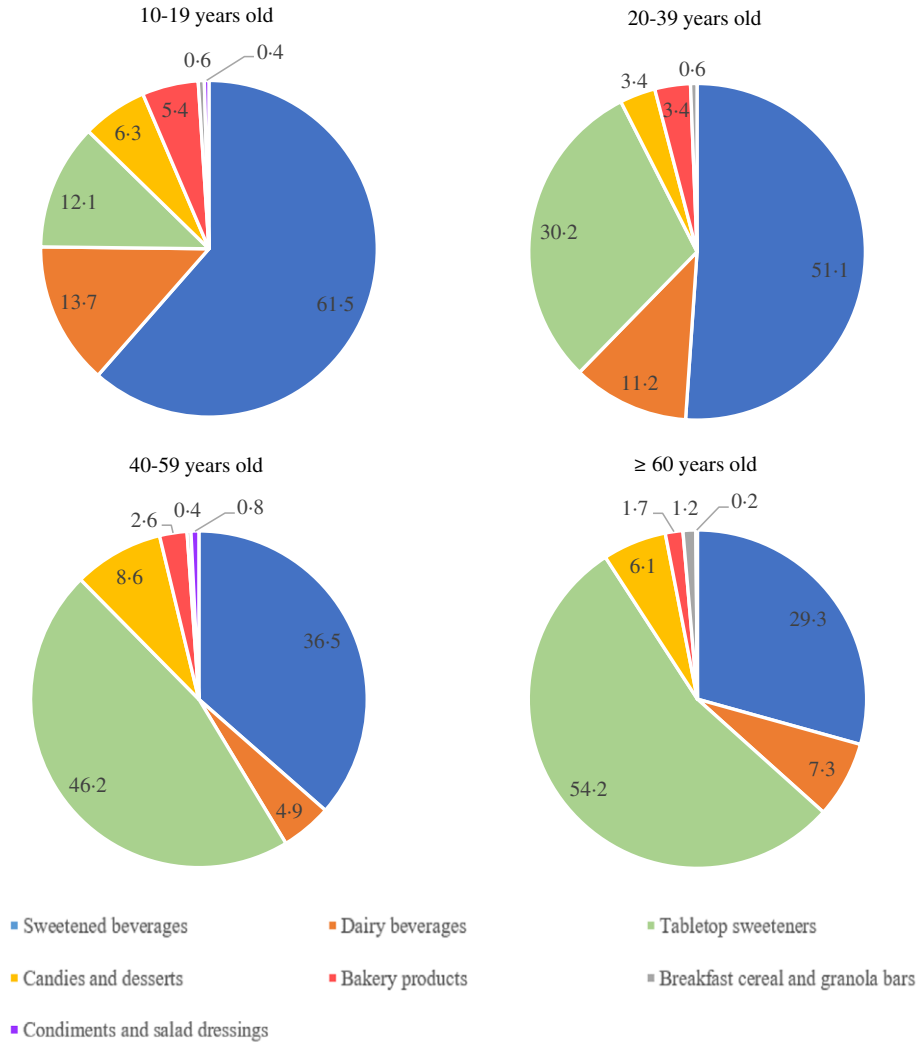

Fig. 2. Most consumed foods and beverages containing low-calorie sweeteners by age group. Campinas, SP, 2015/16.

LCS-containing foods and beverages by income for 40–59-year-olds only. Evidence suggests that the intention to limit sugar in the diet is associated with more education, which might increase the chance of choosing foods and beverages sweeteened with LCS[67]. LCS are found in foods and beverages sold in Brazil that are frequently consumed by individuals of all ages and income levels; such foods include sweetened beverages, breakfast cereals and granola bars[12]. Sugary beverages comprise some of the most consumed ultra-processed foods by Brazilian adolescents; according to the 2017–2018 Brazilian Family Budget Survey, 5·4 % of the calories in an adolescent's diet come from sugary beverages (soft drinks, dairy beverages and other sweetened beverages)[14], which were also the top contributors to LCS consumption in our sample of adolescents.

The ubiquity of LCS in products sold in Brazil likely contributed to our findings[12]. A recent study showed that 40 % of packaged foods and beverages sold in Brazil did not have any LCS-related front-of-package claims, such as "diet", "light", "low sugar" and "sugar free". These products may have LCS alone or in addition to added sugars, and it is not easy for consumers to find information to make informed purchasing decisions regarding their intentions to consume LCS-containing foods and beverages[12].

We also estimated population dietary exposure to high levels of LCS. The assessment of population dietary exposure to high levels of LCS posed important challenges related to the unavailability of label information on the quantities of LCS added to foods and beverages[42]; thus, there were inherent difficulties in estimating the dietary intake of LCS[35]. Although 24-h food recalls are considered to be the gold standard for assessing population dietary intake, LCS-containing foods and beverages might be neglected if the survey does not intend to assess these additives. By proposing three different scenarios of LCS consumption, we aimed to mitigate the uncertainties in our estimates. Similar to other findings in the Brazilian population[39,68], our estimates of population dietary exposure to LCS did not exceed the ADI levels for any of the assessed LCS. More detailed assessments of dietary exposure to high levels of LCS are found in European countries due to local regulations that require all

British Journal of Nutrition

Table 1. Consumption of foods and beverages containing low-calorie sweeteners by age group. Campinas, SP, 2015/16

	Population		Consumption of LCS-containing foods and beverages			
	%	95 % CI	Crude estimate (%)	95 % CI	Adjusted PR	95 % CI
10–19 years old						
Age (years)						
10–14	47·4	43·7, 51·2	43·0	36·46, 49·78	Ref	
15–19	52·6	48·8, 56·3	42·5	37·41, 47·77	1·0	0·8, 1·2
Sex						
Male	48·9	45·5, 52·2	43·8	37·27, 50·5	Ref	
Female	51·2	47·8, 54·5	41·7	36·13, 47·58	0·9	0·8, 1·2
Skin colour						
Non-white	44·2	38·8, 49·8	42·1	36·7, 47·64	Ref	
White	55·8	50·2, 61·2	43·2	37·48, 49·18	1·0	0·9, 1·2
Caregiver education (years)						
< 8	37·3	31·5, 43·5	43·4	37·51, 49·44	Ref	
8–11	44·5	40·1, 49·0	42·8	36·64, 49·21	1·0	0·8, 1·1
> 12	18·2	14·2, 23·1	41·0	31·46, 51·18	0·9	0·7, 1·2
Per capita household income (minimum wage)						
< 1	59·4	52·1, 66·4	40·6	35·0, 46·32	Ref	
1–3	38·7	32·1, 45·7	46·0	39·7, 52·53	1·2	1·0, 1·4
> 3	1·9	1·1, 3·2	46·4	25·7, 68·38	1·2	0·7, 2·1
20–39 years old						
Sex						
Male	53·3	49·4, 57·2	44·0	36·4, 52·0	Ref	
Female	46·7	42·8, 50·6	42·6	34·9, 50·7	1·0	0·8, 1·2
Skin colour						
Non-white	38·4	32·3, 44·8	44·1	37·5, 50·9	Ref	
White	61·6	55·2, 67·7	42·9	34·7, 51·5	0·9	0·7, 1·2
Education level (years)						
< 8	13·8	9·1, 20·2	40·0	27·9, 53·5	Ref	
8–11	45·1	39·2, 51·2	39·2	32·9, 45·9	1·0	0·7, 1·4
> 12	41·1	33·3, 49·4	49·1	37·6, 60·6	1·2	0·8, 1·8
Per capita household income (minimum wage)						
< 1	41·4	32·8, 50·6	41·9	34·1, 50·2	Ref	
1–3	45·3	37·6, 53·3	42·7	34·1, 51·7	1·0	0·7, 1·2
> 3	13·3	8·1, 21·0	50·5	31·6, 69·3	1·1	0·6, 1·7
40–59 years old						
Sex						
Male	54·2	49·6, 58·7	43·4	36·8, 50·1	Ref	
Female	45·8	41·3, 50·4	49·1	41·5, 56·8	1·2	0·9, 1·5
Skin colour						
Non-white	30·5	24·5, 37·2	46·0	38·5, 53·8	Ref	
White	69·5	62·8, 75·5	46·0	39·9, 52·2	1·0	0·8, 1·2
Education level (years)						
< 8	35·2	29·4, 41·4	43·0	34·9, 51·5	Ref	
8–11	38·4	32·7, 44·4	44·7	36·7, 53·0	1·1	0·8, 1·4
> 12	26·4	20·5, 33·3	52·4	42·8, 62·0	1·4	1·1, 1·8
Per capita household income (minimum wage)						
< 1	32·1	25·7, 39·3	47·9	38·9, 57·0	Ref	
1–3	52·9	46·3, 59·4	47·8	41·0, 54·6	0·9	0·7, 1·2
> 3	15·0	10·4, 21·1	35·9	23·3, 50·8	0·6	0·4, 1·0
≥ 60 years old						
Sex						
Male	56·7	53·7, 59·8	46·3	41·3, 51·4	Ref	
Female	43·3	40·2, 46·3	44·8	38·6, 51·2	1·0	0·8, 1·1
Skin colour						
Non-white	30·9	25·3, 37·1	43·8	37·3, 50·5	Ref	
White	69·1	62·9, 74·7	46·5	41·9, 51·2	1·0	0·9, 1·2
Education level (years)						
< 8	68·1	63·1, 72·8	44·3	39·6, 49·1	Ref	
8–11	18·5	15·1, 22·3	47·9	37·8, 58·2	1·0	0·8, 1·3
> 12	13·4	9·8, 18·1	49·5	38·0, 61·1	1·0	0·8, 1·3
Per capita household income (minimum wage)						
< 1	29·0	24·0, 34·4	44·0	37·4, 50·9	Ref	
1–3	55·6	50·3, 60·8	43·9	37·7, 50·4	1·0	0·8, 1·2
> 3	15·4	11·4, 20·5	56·0	46·8, 64·8	1·2	0·9, 1·6

LCS, low-calorie sweetener; PR, prevalence ratio.

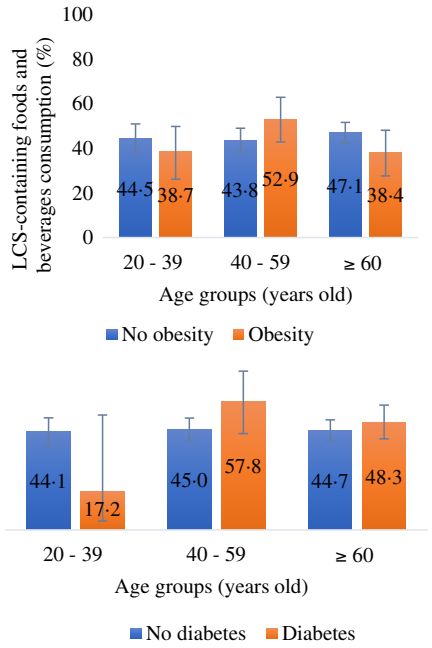

Fig. 3. Consumption of foods and beverages containing low-calorie sweeteners among participants aged 20 years or older with and without obesity or diabetes. Campinas, SP, 2015/16. LCS, low-calorie sweeteners. Bars: 95% CI.

Member States to monitor the intake of additives at the population level. Such requirements encourage the use of standardised assessment methods[69]. A cohort study that investigated the consumption of additives in France found that acesulfame potassium and sorbitol were some of the most frequently consumed food additives, with approximately one-third of the population consuming those LCS[70].

Nonetheless, the established ADI levels can be used by epidemiologists who seek to estimate population exposure to high levels of LCS and to monitor and understand the adverse short- and long-term effects of LCS consumption at the population level. Toxicological investigations are conducted to determine the ADI levels of food additives that are allowed to be used in foods and beverages. However, these investigations often include selected health outcomes and may have been conducted before imposing limits on using certain food additives in products[71]. Recent epidemiological studies have raised concerns about the consumption of food additives; LCS have been the subject of recent systematic reviews and meta-analyses, and they have reinforced that further research is needed to better understand the long-term risks of LCS[58,62,72]. Although toxicity tests are often used to assess LCS[12,70,73], these tests do not take into account synergies among the additives and other dietary components. Taken together, our limitations in accurately assessing the exposure of the studied population to high levels of LCS, and the intrinsic complexities associated with assessing long-term and population-level risk limits prevent us from safely concluding that the studied sample is free from exposure risk.

Technological advances in the development of new LCS types[74,75] and the ability to combine different LCS without exceeding the individual ADI levels[76] can increase the population's exposure to high levels of LCS. In the case of substances with contradictory evidence, such as LCS, the suggestion for public health purposes is to limit population exposure to the substance[77]. Meanwhile, to guarantee that the population will not be exposed to high levels of LCS, a more standardised approach to monitor changes in dietary exposure in combination with monitoring the LCS levels in foods and beverages, LCS toxicity and LCS health effects[78] is key, especially in the presence of sugar reduction strategies[78].

This study has some limitations in addition to the those that affected the reliability of the employed dietary assessment methods[79] and the intricacies in assessing population dietary exposure to high levels of LCS. First, to minimise uncertainties in measuring the consumption of these additives that were related to difficulties in assessing LCS concentrations in foods and beverages[35], we determined whether a food or beverage item reported in the 24-h food recall contained LCS by using available secondary data about the brand market share and about the food or beverage nutrition composition. Second, we were unable to quantify tabletop sweetener consumption and therefore used previously reported average intake estimates of Brazilians[6]. Third, Brazilian legislation does not require food companies to disclose quantities of LCS in most packaged foods and beverages[42]. To overcome this barrier, we assumed the items contained the maximum LCS limit permitted in the food or beverage[38] and used the average concentration of tabletop sweeteners sold in the country[44].

An important strength of our study is the extra steps taken to refine the LCS data by using food labels[37] and other information. Our study is the first to employ various methods to more accurately estimate the consumption of LCS in a population-based sample of Brazilian adolescents, adults and older adults. Our findings contribute to the literature by providing evidence on the levels of consumption of LCS-containing foods and beverages in Brazil and on the top sources of LCS in the Brazilian diet. Our findings shed light on the urgency to improve LCS consumption assessment methods in the face of the widespread prevalence of LCS-containing foods and beverages sold in the country, including products marketed to children[12]. Our findings also have implications for the implementation of food and nutrition policies that will reduce the sugar content of the Brazilian diet. Evidence from countries in which such policies were enacted shows that foods were often reformulated to include LCS; thus, there has been an increased prevalence of LCS-containing foods and beverages[29,80].

Conclusion

The prevalence of consuming LCS-containing foods and beverageswas high in all age groups, across all socio-economic strata, and regardless of the presence of obesity or diabetes. Tabletop sweeteners were the top source of LCS in the diet of older participants (> 40 years), while sweetened beverages were the top source in the diet of younger participants (≤ 40 years). Because of our current limited capacity to estimate population dietary exposure to high levels of LCS and the unclear evidence linking LCS to better health outcomes, our findings are concerning and

highlight the need for the development of improved LCS consumption assessment methods and closer monitoring of its consumption.

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Supplementary material

For supplementary material/s referred to in this article, please visit https://doi.org/10.1017/S0007114522003002

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