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Basic nutritional investigation

Fructose content in popular beverages made with and without high-fructose corn syrup☆

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ABSTRACT

Objective: Excess fructose consumption is hypothesized to be associated with risk for metabolic disease. Actual fructose consumption levels are difficult to estimate because of the unlabeled quantity of fructose in beverages. The aims of this study were threefold: 1) re-examine the fructose content in previously tested beverages using two additional assay methods capable of detecting other sugars, especially maltose, 2) compare data across all methods to determine the actual free fructose-to-glucose ratio in beverages made either with or without high-fructose corn syrup (HFCS), and 3) expand the analysis to determine fructose content in commonly consumed juice products.

Methods: Sugar-sweetened beverages (SSBs) and fruit juice drinks that were either made with or without HFCS were analyzed in separate, independent laboratories via three different methods to determine sugar profiles.

Results: For SSBs, the three independent laboratory methods showed consistent and reproducible results. In SSBs made with HFCS, fructose constituted 60.6% ± 2.7% of sugar content. In juices sweetened with HFCS, fructose accounted for 52.1% ± 5.9% of sugar content, although in some juices made from 100% fruit, fructose concentration reached 65.35 g/L accounting for 67% of sugars.

Conclusion: Our results provide evidence of higher than expected amounts of free fructose in some beverages. Popular beverages made with HFCS have a fructose-to-glucose ratio of approximately 60:40, and thus contain 50% more fructose than glucose. Some pure fruit juices have twice as much fructose as glucose. These findings suggest that beverages made with HFCS and some juices have a sugar profile very different than sucrose, in which amounts of fructose and glucose are equivalent. Current dietary analyses may underestimate actual fructose consumption.

Introduction

Assessment of fructose content in foods and beverages is an important public health issue to consider, as Americans consume more per-capita high-fructose corn syrup (HFCS) than any other nation [1]. Fructose consumption in the U.S. population has doubled over the past 3 decades [2] and the consumption of excess fructose, due primarily to the way in which fructose is specifically metabolized by the liver [3,4], has been linked to fatty liver disease [5], dyslipidemia [6], type 2 diabetes [1], obesity [7], and gout [8]. However, others have posted that fructose is no different than sucrose, without any adverse health effects [9], and that HFCS-55 is roughly equivalent [10] to or similar in composition [11] to sucrose. A growing body of clinical evidence suggests that fructose consumption plays a direct role in the risk for metabolic disease [12,13] and may have adverse effects on central appetite regulation compared with glucose [14]. Despite this evidence, current food-labeling practices do not provide information on fructose content in foods and beverages made with HFCS, fruit juice concentrate or crystalline fructose,

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all of which contain fructose and are being used in increasing amounts as added sugar in the food supply [15]. Because there are currently no disclosures of fructose content in foods and beverages [15], and many nutrition databases only rely on product label information, it is challenging to accurately determine actual fructose consumption levels in nutrition research.

Previous work has shown that the fructose content of sugar-sweetened beverages (SSBs) made with HFCS can be as high as 65% of total sugar content, higher than that suggested by the fructose content of HFCS-55 (55% fructose) [16], potentially contributing to unexpectedly more fructose in the diet. However, this initial study was criticized [17] for not measuring other trace sugars (e.g., maltose) thought to be present in SSBs made with HFCS. Therefore, the aims of the present study were to: 1) re-examine the fructose content in previously tested beverages using two additional assay methods capable of detecting other sugars, especially maltose; 2) compare data across all methods to determine the actual free fructose-to-glucose (F:G) ratio in beverages made either with or without HFCS, and 3) expand the analysis to determine fructose content in commonly consumed juice products.

Methods and procedures

Based on product popularity [18], we selected 10 of the 23 beverages, that were previously tested using liquid chromatography (LC) [16], for follow-up analysis using two alternative methods to determine sugar content: 1) a metabolomics-type (MET) approach based on mass spectrometry (MS) with combined liquid and gas chromatography (GC) and 2) GC. Additionally, we extended the use of GC to analyze a selection of juice products, as described here.

Metabolomics-type approach

Popular SSBs were purchased from retailers in East Los Angeles, California, in 2012. Beverages were selected to replicate a previous study [16], in which the selection of beverages was based on consumption frequencies of children in past studies. Nutrition label information and serving size data were recorded. Immediately after opening bottled/canned beverages, 500 μL samples were aliquoted and transferred to Eppendorf cryotubes. All samples were held under refrigeration and sequentially flash frozen in liquid nitrogen within 1 h of the initial transfer. Samples were stored at −20°C overnight before shipment. Glucose, fructose, sucrose, and maltose standard solutions were created from research grade reagents (Sigma-Aldrich, St. Louis, MO, USA) to serve as controls. Ten grams of the sucrose, fructose, and glucose reagents were added to 100 mL of Millipore water and brought into solution. Two concentrations of maltose were prepared, 10 g/L and 1 g/L. Finally, a 50:50 solution of fructose and sucrose was prepared by combining 5 g of each reagent with 100 mL of water. These sugar standard concentrations were chosen to replicate the approximate sugar-content equivalents found in most sweetened beverages with the two maltose preparations representing the very small amounts of this sugar that may be found in sweetened beverages. For all standards, 500 μL aliquots were taken and prepared as previously described. All samples were shipped overnight packed in dry ice to Metabolon (Research Triangle Park, Durham, NC, USA). Samples were split into equal parts for analysis on the gas chromatography/mass spectrometry (GC/MS) and liquid chromatography/mass spectrometry (LC/MS) platforms based on previously published methodology [19]. The GC column was 5% phenyl and the temperature ramp was from 40°C to 300°C in a 16-min period. Samples were analyzed on a Thermo-Finnigan Trace DSQ fast-scanning single-quadrupole MS using electron impact ionization. The LC/MS portion of the platform was based on a Waters ACQUITY UPLC and a Thermo-Finnigan LTQ MS, which consisted of an electrospray ionization source and linear ion-trap mass analyzer. Compounds were identified by comparison to library entries of purified standards or recurrent unknown entities. Identification of known chemical entities was based on comparison to metabolomic library entries of purified standards. The combination of chromatographic properties and mass spectra gave an indication of a match to the specific compound or an isobaric entity. Metabolon was blinded to the source of all samples and standards and samples were analyzed according to previously described methodologies using a metabolomics approach to examine a broad array of simple and complex sugars [19]. Data for sucrose, glucose, fructose and maltose are presented in this manuscript.

Gas chromatography

The 10 SSBs analyzed in the MET analysis were again selected along with 4 additional randomly selected SSBs and 20 other juice products. Online shopping databases for Walmart, SuperValu, and Safeway were accessed to select samples. To control for location and inventory, online store inventories were selected within a defined zip code region (90033). Twenty juices were randomly selected by choosing every 10th product in the retailers' databases until 10 products made with HFCS and 10 products made without HFCS, according to package ingredients labels, were selected. One juice product was omitted from the analysis due to handling error, resulting in 19 products that proceeded to assay. All samples were aliquoted to sterile, sealed containers and sample weights were determined and recorded. Samples were packaged and shipped overnight on dry ice to Covance Laboratories (Madison, WI, USA) for subsequent blinded analysis via GC, against internal standards, according to previously published methods [20–22]. The sugar profile analysis conducted at Covance was applicable to the determination of fructose, galactose, glucose, sucrose, lactose, and maltose in as little as 10 g of food products, syrups, and beverages using GC, as described later. Once received, samples were prepared in accordance with Covance procedures and sugars were extracted from the homogenized sample with water. Aliquots were dried under inert gas and reconstituted with a hydroxylamine hydrochloride solution in pyridine containing phenyl-β-D-glucoside as the internal standard. The resulting oximes were converted to silyl derivatives with hexamethyldisilazane and trifluoroacetic acid treatment and analyzed by GC [20,21] using a flame ionization detector (Agilent 6890 N). An additional 10% of each sample analytical run was tested in duplicate and validated against two internal validated controls. Results underwent quality control comparison with internal validated controls, linearity expectations, and historical data. The limit of quantitation for most matrices is 0.1%. The relative standard deviations, on a cereal matrix, for fructose, glucose, sucrose, and maltose were 4.9%, 7.4%, 3.2%, and 6.4%, respectively. Specific gravity testing was conducted [22] on all liquid samples to allow the reporting of sugar content in appropriate units of measure.

Comparison of laboratory obtained sugar values versus nutritional database values

The Nutrition Data System for Research (NDSR, University of Minnesota, MN, USA) was used to assemble sugar content data for some of the products included in this study. All SSB and juice products listed in the NDSR database were compared against the GC-determined sugar values. The Nutrition Coordinating Center Food and Nutrient Database served as the source of food composition information in NDSR [23]. The U.S. Department of Agriculture Nutrient Data Laboratory was the primary source of nutrient values and nutrient composition. These values were supplemented by food manufacturers' information and data available in the scientific literature [24]. Standardized, published imputation procedures were applied to minimize missing values [25]. Fructose, sucrose, and glucose contents for all SSBs and juice products, with an exact product match in the NDSR database, were assembled for comparison. NDSR product volumes (fl oz.) varied, thus all product volumes were normalized to 12 fl oz. and sugar amounts in grams were calculated based on the NDSR referent volume. These data were compared against the values obtained through GC, as described previously. The mean GC-obtained sugar contents across matched products were compared with the mean NDSR sugar values across matched products, and percent difference was reported.

Data reporting

Examination of sugar composition in 10 beverages across three different methods

A mean with SD (reflecting the differences between analytical methods) and coefficient of variation (CV) for intermethod variability were calculated for fructose, glucose, sucrose, and maltose to assess consistency across the independent methods (SPSS v18 [SPSS Inc, Chicago, IL, USA]). Percent of total sugar (%TS) was calculated for all measured sugars in the SSBs analyzed via the three methodologies.

SSB and juice GC analysis

Data for individual sugars were reported in the following formats; %TS, concentration of each sugar in grams per liter (g/L) and grams per serving (g/s). Free F:G ratios and the concentration of free fructose ($F_{concentration}$) in each product were also assessed. The raw F:G ($F:G_{Raw}$) was adjusted ($F:G_{Adjusted}$) to account for the additional glucose that the disaccharide maltose may contribute to the overall sugar profile of the products. F:G values were reported using the first number, representing fructose, as the referent (e.g., F:G of 60:40; reported as 60). Formulas used to obtain these values are presented in Table 1.

Table 1
Formulas

1. TS_{Actual}/100 g sample = S + L + M + G + F + GAL
2. % TS in sample = (X g sugar ÷ TS_{Actual}/100 g sample)*100
3. TS_{Actual}/serving size = TS_{Actual}/100 g ÷ (100 / X g/s)
4. Amount individual sugars per serving = X g/100 g ÷ (100 ÷X g/s)
5. Grams G from disaccharide = g M + (0.5*g/L)
6. $F:G_{Raw}$ = [F grams ÷ (F grams + G grams)]*100
7. $F:G_{Adjusted}$ = [F grams ÷ (F grams + G grams + grams G from disaccharide)]*100

F, fructose; F:G, fructose to glucose ratio; G, glucose; GAL, galactose; L, lactose; M, maltose; S, sucrose; TS, total sugar

* Sugar calculations (based on lab results provided in g/100 g sample format).

Results

Fructose content of SSBs: Methodologic comparison

We first compared the fructose content of the original 10 beverages, as measured by three independent methods/laboratories (LC [16], MET, and GC), which are displayed in Figure 1. Results were consistent across all three methodologies for percent fructose and glucose (Fig. 1) as well as sucrose and maltose (Supplementary Fig. 1). Free fructose content was consistent across methodologies with SDs remaining below 3.6%, with the exception of Gatorade (SD = 4.5%). Mean free fructose content, expressed as a percent of all sugars, for beverages listing HFCS as an ingredient was 60.6% ± 2.7%. In all remaining beverages, the mean free fructose content, expressed as %TS, was 35.5% ± 15.4%. Mexican Coca-Cola consistently contained 49.1% ± 3% of total sugar as free fructose despite neither HFCS nor fructose being listed on the label. Additionally, Pepsi Throwback, Gatorade, and Sierra Mist, all which list neither HFCS nor fructose as added sweeteners, contained fructose as a %TS in ~50%, 40%, and 8%, respectively. Analyses confirmed that only very small amounts of maltose (not >1.7% of sugars) were present in the sampled beverages. The CV values for fructose and glucose were consistently less than 0.12 and 0.1, respectively indicating high reliability between measures. Mexican Coca Cola had a glucose CV of 0.2 and an artificially elevated sucrose CV of 0.9 due to the original analysis detecting no sucrose resulting in a very high SD. Sierra Mist was not assayed in the original analysis, therefore no CV was reported. The CV of sucrose in other products was in all cases <0.2. In the MET and GC analyses, maltose was only detected in 4 and 3 of the 10 beverages, respectively and CV values ranged from 0.1 to 0.3, likely due to the very small amounts detected via the two methods. Maltose was not measured in the initial study.

Sugar analysis using gas chromatography

SSBs and juices

Beverages listing HFCS as an ingredient had a mean $F:G_{Adjusted}$ of 59.6 ± 0.5 (Fig. 2). Among products not listing HFCS as a sweetener, the mean $F:G_{Adjusted}$ was 50.7 ± 0.6. $F:G_{Raw}$ values were not altered when adjusted for disaccharides. Mean $F_{concentration}$ in products listing HFCS as an ingredient were 59.4 ± 8.9 g/L versus 30.8 ± 19.5 g/L for non-HFCS products (Fig. 2, Table 2). Sprite, Dr. Pepper, and Pepsi had free fructose accounting for 60% or more of total sugar. Several SSBs that did not list HFCS or fructose as an ingredient on the nutrition label had $F_{concentration}$ substantially greater than zero (Mexican Coca-Cola, 51 g/L; Pepsi Throwback, 42 g/L; Gatorade, 23 g/L; Sierra Mist, 7 g/L). Pepsi lists sucrose as an included ingredient, however, no sucrose was detected in Pepsi using GC methodology and its $F:G_{Adjusted}$ was 60. Maltose was detected in eight products and levels did not exceed 2% of total sugar in any of these beverages. Galactose and lactose were not detected in any of the products (Table 3).

Minute Maid and Juicy Juice 100% apple juices had $F:G_{Adjusted}$ values of 67.1 and 67.3, respectively, the highest in the study. Mean $F_{concentration}$ for these two products were 65.7 and 64.8 g/L, respectively (Fig. 3, Table 4). Five other juices had $F:G_{Adjusted}$ values >55. Hawaiian Punch had the highest $F:G_{Adjusted}$ value (61.5) among the products listing HFCS as an ingredient. Mean $F:G_{Adjusted}$ and $F_{concentration}$ for HFCS products were 52.1 ± 5.9 and 45.7 ± 10.6 g/L, respectively. Mean $F:G_{Adjusted}$ and $F_{concentration}$ for non-HFCS products were 56.7 ± 6.9 and 45.2 ± 16.6 g/L, respectively. Maltose was detected in six products but did not exceed 1.9% of total sugar in any of these beverages. Galactose and lactose were not detected in any of the products (Table 5).

Discussion

This is the first study to comprehensively determine the fructose content and sugar profiles of both SSBs and juice products. The results of the multimethod sugar profile analysis were strikingly similar in terms of fructose content. Prior work demonstrated that in popular SSBs, fructose constituted up to 65% of the total sugar with an average of 59% in beverages made with HFCS [16]. However, this initial analysis may have been methodologically limited [17] in that maltose, which may potentially alter the fructose to glucose ratio, was not measured. In the present study, we used two additional and independent assays that were capable of detecting the presence of trace sugars, including maltose, and confirmed prior findings while also extending the analysis beyond SSBs to also include fruit juices.

The clearest and most consistent finding in this study was that the five most popular [18] HFCS-sweetened sodas made by companies that comprise ~90% of the annual beverage market share [18] (Coca-Cola, Pepsi, Dr. Pepper, Mountain Dew, and Sprite) have F:G ratios of ~60:40, meaning they contain 50% more fructose than glucose. This fructose content differs dramatically from the 50:50 ratio found in sucrose and from the assumed ratio of 55:42 in HFCS-55. These findings, which were confirmed by three independent laboratories and methodologies, were maintained after adjusting for the presence of trace sugars, and support the initial report [16], providing further evidence for the elevated F:G ratios in the most popular SSBs made with HFCS. HFCS can be manufactured to have variable fructose contents [26] and is also available in higher concentrations up to HFCS-90 [27] (90% fructose). One possible explanation of the higher fructose content may be the blending of HFCS-90 with HFCS-55 or glucose syrup [26] to create products with fructose contents higher than HFCS-55. This strategy is both feasible and allowable under current regulations, as current FDA guidelines for use of HFCS-55 as an ingredient only require it to be a "minimum" of 55% fructose [28,29] (with 3% allotted for other, unspecified sugars), and allow the unrestricted sales and use of HFCS-90 [26]. Without specification of the actual fructose content and possible blend of HFCS used, it is unclear exactly how much actual added fructose is contained in food and beverage products sweetened with HFCS. Given that we observed F:G ratios in excess of the expected ratio of 55:42 in some HFCS-containing products, it is not accurate to consider HFCS-55 nutritionally identical to

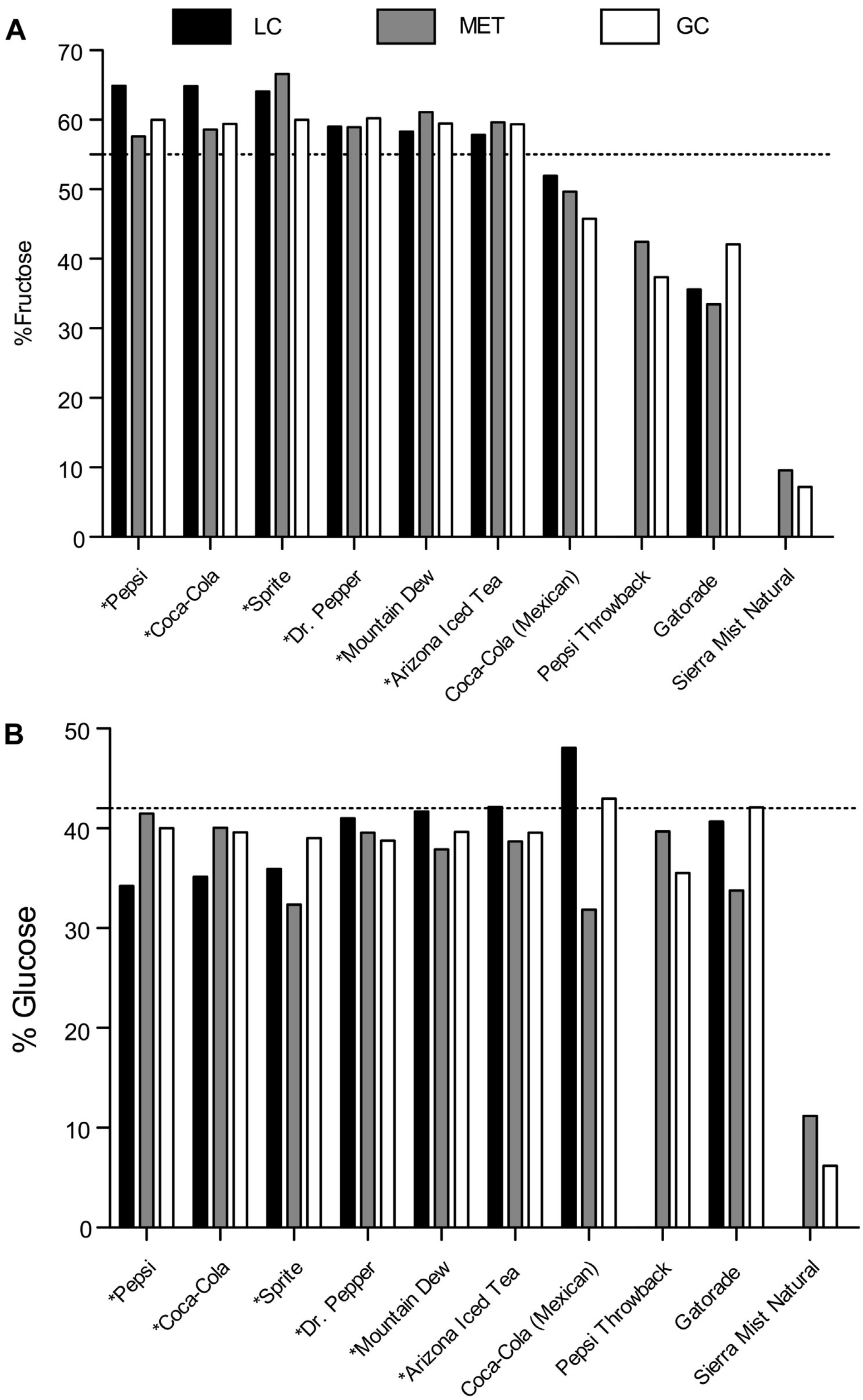

Fig. 1. Mean sugar comparison of sodas across three independent methods. (A) Percent of total sugar shown to be free fructose in soda/sports drink products. Dashed line represents 55% fructose expected of HFCS-55. (B) Percent of total sugar shown to be free glucose in soda/sports drink products. Dashed line represents 42% glucose expected of HFCS-55. Bars represent methodology used to determine sugar profiles: GC, gas chromatography; LC, liquid chromatography; MET, metabolomics. *Products with HFCS listed as an ingredient on the label.

sucrose, which has equal amounts of fructose and glucose [30]. These findings represent a critical public health message. Higher levels of fructose have been consistently linked to metabolic abnormalities [31], yet the current information from HFCS producers suggests that HFCS is only marginally different than sucrose in terms of the F:G ratio.

Sugars not listed on the nutrition labels were detected in several of the SSBs analyzed. For example, Mexican Coca Cola

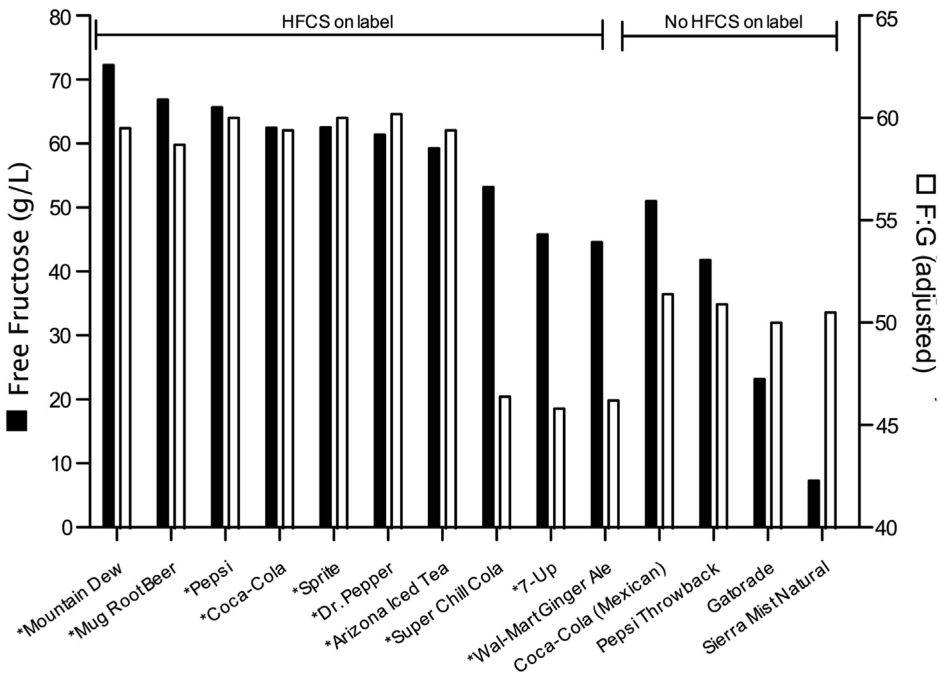

Fig. 2. Fructose concentration and fructose-to-glucose (F:G) ratio: sodas/sports beverages. Concentration of fructose (g/L) in soda/sports drink products is displayed on the left y axis (open bars) and the F:G$_{Adjusted}$ is shown on the right y axis (solid bars). *Products with high-fructose corn syrup (HFCS) listed as an ingredient on the label. F:G$_{Adjusted}$, the F:G ratio adjusted for other detected disaccharides.

had a high free fructose concentration (51 g/L), despite no source of free fructose being listed as an ingredient. Similarly, Pepsi, which lists sugar (sucrose) in addition to HFCS as a sweetener, contained no sucrose when analyzed by three methods and had a consistent F:G ratio of 60:40 suggesting the sole presence of HFCS. Some of these products may be sweetened with hydrolyzed sucrose syrup, or invert sugar, which could conceivably undergo loss of sucrose content through hydrolysis to fructose and glucose monosaccharides in storage, however, it is unlikely that this would fully explain the high concentration of free fructose and high F:G ratios in these products.

In the analysis of juices, we found that the mean fructose concentration among all juices was 45.5 g/L, which is comparable to that of all sodas (50.4 g/L). Minute Maid and Juicy Juice 100% apple juices had the highest F:G ratios. These juices were not sweetened with HFCS, but still had a higher fructose concentration than most sodas. Many juices not containing HFCS use fruit juice concentrate as a sweetener, which is the most commonly listed sweetener in 100% fruit juice products [15]. It is well documented that some natural juices may have high fructose contents, in the absence of HFCS, due to natural fruit sugars, however, juice products often are advertised as a healthy alternative to SSBs. In terms of fructose content, our data suggests that certain juice products may contribute to daily fructose exposure equivalent to, or greater than, that of sodas. Sunny D and Ocean Spray 100% cranberry juice also had F:G ratios of ~60, again suggesting 50% more fructose than glucose in these

Table 2
Sugar concentrations of sodas

Soda/sports drinks	Serving size	FRU		GAL		GLU		LAC		MAL		SUC		TS	
		g/L	g/s	g/L	g/s	g/L	g/s	g/L	g/s	g/L	g/s	g/L	g/s	g/L	g/s
Mountain Dew	591 mL	72.31	42.74	0.00	0.00	48.21	28.49	0.00	0.00	1.05	0.62	0.00	0.00	121.57	71.85
Mug Root Beer	335 mL	66.94	22.43	0.00	0.00	46.02	15.42	0.00	0.00	1.05	0.35	0.00	0.00	114.01	38.19
Pepsi	591 mL	65.71	38.83	0.00	0.00	43.81	25.89	0.00	0.00	0.00	0.00	0.00	0.00	109.52	64.72
Sprite	591 mL	62.52	36.95	0.00	0.00	40.64	24.02	0.00	0.00	1.05	0.62	0.00	0.00	104.20	61.58
Coca-Cola	591 mL	62.52	36.95	0.00	0.00	41.68	24.63	0.00	0.00	1.04	0.62	0.00	0.00	105.24	62.20
Dr. Pepper	591 mL	61.42	36.30	0.00	0.00	39.56	23.38	0.00	0.00	1.04	0.62	0.00	0.00	102.02	60.29
Arizona Iced Tea With Lemon Flavor	240 mL	59.28	14.23	0.00	0.00	39.52	9.48	0.00	0.00	1.04	0.25	0.00	0.00	99.84	23.96
Super Chill Cola (SuperValu brand)	240 mL	53.24	12.78	0.00	0.00	59.51	14.28	0.00	0.00	2.09	0.50	0.00	0.00	114.84	27.56
Coca-Cola (Mexican)*	335 mL	51.01	17.09	0.00	0.00	47.89	16.04	0.00	0.00	0.00	0.00	12.49	4.18	111.39	37.31
7-Up	591 mL	45.80	27.07	0.00	0.00	53.09	31.38	0.00	0.00	1.04	0.62	0.00	0.00	99.94	59.06
Ginger Ale (caffeine-free) (Walmart Brand)	240 mL	44.63	10.71	0.00	0.00	50.86	12.21	0.00	0.00	1.04	0.25	0.00	0.00	96.53	23.17
Pepsi Throwback*	591 mL	41.84	24.73	0.00	0.00	39.75	23.49	0.00	0.00	0.00	0.00	30.33	17.93	111.92	66.15
Gatorade Lemon-Lime*	355 mL	23.19	8.23	0.00	0.00	24.58	8.23	0.00	0.00	0.00	0.00	8.70	3.09	55.08	19.55
Sierra Mist Natural*	591 mL	7.28	4.30	0.00	0.00	6.24	3.69	0.00	0.00	0.00	0.00	87.36	51.63	100.88	59.62

FRU, fructose; GAL, galactose; GLU, glucose; LAC, lactose; MAL, maltose; SUC, sucrose; TS, total sugar; g/L, grams per liter; g/s, grams per serving
Sugar concentrations by per serving size and per liter values
* Products not listing high-fructose corn syrup as an ingredient.

Table 3
Sugar profile of sodas

Soda	% Fructose	% Glucose	% Sucrose	% Maltose	% Galactose	% Lactose
Dr. Pepper	60.20	38.78	0.00	1.02	0.00	0.00
Pepsi	60.00	40.00	0.00	0.00	0.00	0.00
Sprite	60.00	39.00	0.00	1.00	0.00	0.00
Mountain Dew	59.48	39.66	0.00	0.86	0.00	0.00
Coca-Cola	59.41	39.60	0.00	0.99	0.00	0.00
Arizona Iced Tea	59.38	39.58	0.00	1.04	0.00	0.00
Mug Root Beer	58.72	40.37	0.00	0.92	0.00	0.00
Super Chill Cola	46.36	51.82	0.00	1.82	0.00	0.00
Walmart Ginger Ale	46.24	52.69	0.00	1.08	0.00	0.00
7-Up	45.83	53.13	0.00	1.04	0.00	0.00
Coca-Cola (Mexican)*	45.79	42.99	11.21	0.00	0.00	0.00
Gatorade Lemon-Lime*	42.11	42.11	15.79	0.00	0.00	0.00
Pepsi Throwback*	37.38	35.51	27.10	0.00	0.00	0.00
Sierra Mist Natural*	7.22	6.19	86.60	0.00	0.00	0.00

Values for each sugar represent percentage of total sugar in product
* Products not listing high-fructose corn syrup as an ingredient.

products. Although these products likely contain natural fruit sugars (fructose), the overall sugar profiles are strikingly similar to those of SSBs sweetened with HFCS. When total fructose exposure is considered (free fructose plus fructose from sucrose), juices contained a mean concentration of fructose almost equivalent to that of sodas (51.4 versus 55.7 g/L, respectively). Although sodas are the most consumed source of SSBs in adults and children, juice consumption has increased in adolescent and minority populations in recent years [32]. Considering larger serving sizes, higher daily consumption rates of juices, and the more common use of fruit juice concentrate or HFCS in these products, there is likely a higher than expected daily fructose consumption in the population from juice products that supports the need for further research on the metabolic consequences of high-fructose-containing juice intake.

Taken together, our chemical analyses of sugar content, which are fundamentally different from current database estimates, indicate that in many cases, SSB and juice products can contain upward of 5% to 15% more free fructose than would be expected based on the assumed ratio in HFCS-55. Additionally, when laboratory-determined sugar values were compared with nutrient data from matched products in the NDSR database, we show that NDSR values underestimate mean fructose content for SSBs and juices by 22% and 14%, respectively (Supplementary Tables 1 and 2). Many nutritional product databases rely on product nutrition labels for nutrient data. Given the ambiguity surrounding the exact sugar composition of sodas and juices, food producers may not know the exact amount of fructose contained in the HFCS used. Our findings illustrate the high degree of variability between actual sugar content versus product label values and nutritional database values for some SSBs and juices. These data challenge existing estimates of fructose content and suggest that prior population-based studies reporting fructose or HFCS consumption [33–35] likely underestimate actual fructose consumption.

Based on National Health and Nutrition Examination Survey (NHANES) data from 1988 to 1994, mean intake of fructose among children and adults was 54.7 g/d, however, adolescents ages 12–18 y consumed 72.8 g/d [36] of fructose. More recently, 1999–2004 NHANES data showed that young males (15–18 y) in the 95th percentile of fructose consumption, consume 121 g/d of fructose [36]. This value is twice as high than when assessed in 1978 [34] and 10 times higher than the 6 g/d per-capita value used to determine the safety of

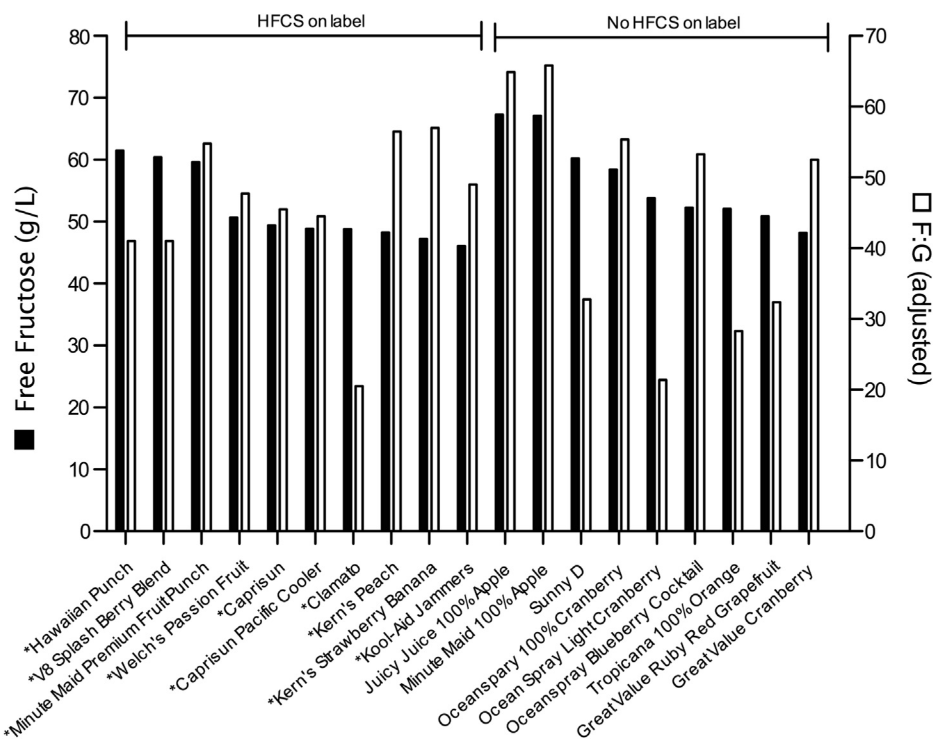

Fig. 3. Fructose concentration and fructose-to-glucose (F:G) ratio: juices. Concentration of fructose (g/L) in juices is displayed on the left y axis (open bars) and the $F:G_{Adjusted}$ is shown on the right y axis (solid bars). * Products with high-fructose corn syrup listed as an ingredient on the label. $F:G_{Adjusted}$, the F:G ratio adjusted for other detected disaccharides.

Table 4
Sugar concentrations of juices

Juice	Serving size	FRU		GAL		GLU		LAC		MAL		SUC		TS	
		g/L	g/s	g/L	g/s	g/L	g/s	g/L	g/s	g/L	g/s	g/L	g/s	g/L	g/s
Minute Maid 100% Apple Juice*	450 mL	65.77	29.60	0.00	0.00	28.19	12.68	0.00	0.00	0.00	0.00	15.66	7.05	109.62	49.33
Juicy Juice 100% Apple Juice*	200 mL	64.85	12.97	0.00	0.00	27.20	5.44	0.00	0.00	0.00	0.00	16.74	3.35	108.78	21.76
Kern's Nectar Strawberry Banana	340 mL	56.97	19.37	0.00	0.00	63.30	21.52	0.00	0.00	1.06	0.36	9.50	3.23	130.82	44.48
Kern's Nectar Peach	340 mL	56.48	19.20	0.00	0.00	59.62	20.27	0.00	0.00	1.05	0.36	6.28	2.13	123.43	41.97
Ocean Spray 100%* Cranberry Juice	240 mL	55.44	13.31	0.00	0.00	38.70	9.29	0.00	0.00	0.00	0.00	5.23	1.26	99.37	23.85
Minute Maid Premium Fruit Punch	240 mL	54.80	13.15	0.00	0.00	36.19	8.69	0.00	0.00	1.03	0.25	0.00	0.00	92.03	22.09
Ocean Spray Blueberry Juice Cocktail*	240 mL	53.30	12.79	0.00	0.00	48.07	11.54	0.00	0.00	0.00	0.00	14.63	3.51	116.00	27.84
Great Value Cranberry*	240 mL	52.50	12.60	0.00	0.00	56.70	13.61	0.00	0.00	0.00	0.00	9.45	2.27	118.65	28.48
Kool-Aid Jammers	177 mL	49.02	8.68	0.00	0.00	55.28	9.78	0.00	0.00	2.09	0.37	0.00	0.00	106.39	18.83
Welch's Passion Fruit	240 mL	47.70	11.45	0.00	0.00	45.58	10.94	0.00	0.00	0.00	0.00	49.82	11.96	143.10	34.34
Capri Sun	177 mL	45.50	8.05	0.00	0.00	45.50	8.05	0.00	0.00	1.03	0.18	0.00	0.00	92.03	16.29
Capri SunPacific Cooler	177 mL	44.51	7.88	0.00	0.00	45.54	8.06	0.00	0.00	1.04	0.18	0.00	0.00	91.08	16.12
V8 Splash Berry Blend	240 mL	41.00	9.84	0.00	0.00	26.65	6.40	0.00	0.00	0.00	0.00	1.03	0.25	68.68	16.48
Hawaiian Punch	240 mL	40.96	9.83	0.00	0.00	25.60	6.14	0.00	0.00	0.00	0.00	0.00	0.00	66.56	15.97
Sunny D*	473 mL	32.77	15.50	0.00	0.00	21.50	10.17	0.00	0.00	0.00	0.00	1.02	0.48	55.30	26.16
Great Value Ruby Red Grapefruit*	240 mL	32.36	7.77	0.00	0.00	30.28	7.27	0.00	0.00	0.00	0.00	48.02	11.53	110.66	26.56
Tropicana 100% Juice*	240 mL	28.27	6.78	0.00	0.00	24.08	5.78	0.00	0.00	0.00	0.00	47.12	11.31	99.47	23.87
Ocean Spray Light Cranberry Juice*	240 mL	21.44	5.15	0.00	0.00	18.38	4.41	0.00	0.00	0.00	0.00	0.00	0.00	39.82	9.56
Clamato	240 mL	20.50	4.92	0.00	0.00	21.53	5.17	0.00	0.00	0.00	0.00	0.00	0.00	42.03	10.09

FRU, fructose; GAL, galactose; GLU, glucose; LAC, lactose; MAL, maltose; SUC, sucrose; TS, total sugar; g/L, grams per liter; g/s, grams per serving
Sugar concentrations by per serving size and per liter values
* Products not listing high-fructose corn syrup as an ingredient.

consumption in 1976 [37]. Fructose can induce metabolic syndrome in both animal models and humans [38] and fructose exposure at the levels described here has been shown to be metabolically deleterious in humans [39–41]. It is plausible that additional, unlabeled amounts of fructose contained in SSBs and juices can add up and, in combination with other commonly consumed high-fructose-containing foods, can lead to fructose intake >100 g/d. Thus, the differentiation between specific types of sugars (especially fructose) in popular beverages, and the accurate quantification of their presence, are crucial to informing responsible consumption of these products [42] and represent a critical opportunity to affect public health.

In conclusion, this study supports and strengthens previous findings regarding the fructose content of SSBs and provides new information on the sugar composition and overall fructose content of commonly consumed SSB and juice products. The results support the initial findings [16], suggesting that the most popular sodas made with HFCS as the sole added sweetener have an F:G ratio of 60:40, indicating 50% more fructose than glucose and a meaningful difference from the equivalent F:G ratio observed in table sugar (sucrose). The sugars galactose and lactose were not present and maltose was only detected in very small amounts in these products. As expected, certain fruit juices contained fructose, however, some contained more total fructose than sodas, often with 50% more fructose than glucose. Although SSBs are a major source of fructose in the diet of Americans, our results demonstrate that juice products may contribute substantially to total daily fructose consumption as well. Based on these findings, current population estimates of fructose consumption determined via existing food nutrient data are likely underestimated.

Table 5
Sugar profile of juices

Juice	% Fructose	% Glucose	% Sucrose	% Maltose	% Galactose	% Lactose
Hawaiian Punch	61.54	38.46	0.00	0.00	0.00	0.00
Minute Maid 100% Apple*	60.00	25.71	14.29	0.00	0.00	0.00
V8 Splash Berry Blend	59.70	38.81	1.49	0.00	0.00	0.00
Juicy Juice 100% Apple*	59.62	25.00	15.38	0.00	0.00	0.00
Minute Maid Premium Fruit Punch	59.55	39.33	0.00	1.12	0.00	0.00
Sunny D	59.26	38.89	1.85	0.00	0.00	0.00
Ocean Spray 100% Cranberry*	55.79	38.95	5.26	0.00	0.00	0.00
Ocean Spray Light Cranberry*	53.85	46.15	0.00	0.00	0.00	0.00
Capri Sun	49.44	49.44	0.00	1.12	0.00	0.00
Capri SunPacific Cooler	48.86	50.00	0.00	1.14	0.00	0.00
Clamato	48.78	51.22	0.00	0.00	0.00	0.00
Kool-Aid Jammers	46.08	51.96	0.00	1.96	0.00	0.00
Ocean Spray Blueberry*	45.95	41.44	12.61	0.00	0.00	0.00
Kern's Peach	45.76	48.31	5.08	0.85	0.00	0.00
Great Value Cranberry*	44.25	47.79	7.96	0.00	0.00	0.00
Kern's Strawberry Banana	43.55	48.39	7.26	0.81	0.00	0.00
Welch's Passion Fruit	33.33	31.85	34.81	0.00	0.00	0.00
Great Value Ruby Red Grapefruit*	29.25	27.36	43.40	0.00	0.00	0.00
Tropicana 100% Orange*	28.42	24.21	47.37	0.00	0.00	0.00

Values for each sugar represent percentage of total sugar in product
* Products not listing high-fructose corn syrup as an ingredient.

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Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.nut.2014.04.003.

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