Food and Chemical Toxicology 49 (2011) 2875–2882

Contents lists available at SciVerse ScienceDirect

Food and Chemical Toxicology

journal homepage: www.elsevier.com/locate/foodchemtox

# Fructose and non-fructose sugar intakes in the US population and their associations with indicators of metabolic syndrome

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ARTICLE INFO

*Article history:*
Received 26 April 2011
Accepted 23 July 2011
Available online 25 August 2011

*Keywords:*
Fructose
High-fructose-corn-syrup
Metabolic syndrome
Uric acid
NHANES

ABSTRACT

*Background:* Relationships of sugar intakes with indicators of metabolic syndrome are important concerns for public health and safety. For individuals, dietary intake data for fructose and other sugars are limited.
*Method:* Descriptive statistics. The data from 25,506 subjects, aged 12–80 yr, contained in the NHANES 1999–2006 databases were analyzed for sugar intakes and health parameters.
*Results:* Dietary fructose was almost always consumed with other sugars. On average, fructose provided 37% of total simple sugar intake and 9% of energy intake. In more than 97% of individuals studied, fructose caloric contribution was lower than that of non-fructose sugars. Fructose and non-fructose sugar intakes had no positive association with blood concentrations of TG, HDL cholesterol, glycohemoglobin, uric acid, blood pressure, waist circumference, and BMI in the adults studied (aged 19 to 80 yr, $n = 17{,}749$).
*Conclusion:* Daily fructose intakes with the American diet averaged approximately 37% of total sugars and 9% of daily energy. Fructose was rarely consumed solely or in excess over non-fructose sugars. Fructose and non-fructose sugar ordinary consumption was not positively associated with indicators of metabolic syndrome, uric acid and BMI.



## 1. Introduction

Obesity, metabolic syndrome, and diabetes prevalence have continued to rise to the point of becoming primary public health issues. Based on newly updated data by NIH or AHA, the prevalence rates of obesity or metabolic syndrome have reached about one third of the US population aged 20 yr and over (AHA, 2010; NIH, 2010). The rate of diabetes is over 11% in the same adult population (NIH, 2011). Various factors correlated with the prevalence have been proposed. Several reviews have concluded that intakes of fructose or high fructose corn syrup (HFCS) were associated with increased risk of obesity or metabolic syndrome (Bray, 2004; Hu and Malik, 2010; Stanhope and Havel, 2008; Stanhope and Havel, 2010). However, other reviews have not reached this conclusion (Anderson, 2007; Dolan et al., 2010; Forshee et al., 2007; Jones, 2009; Livesey and Taylor, 2008; Mattes et al., 2010; Tappy and Le, 2010; Tappy et al., 2010; White, 2008). Unlike obesity, there are no single well-accepted criteria for defining the metabolic syndrome (Alberti et al., 2009). The American Heart Association and the National Heart, Lung, and Blood Institute recommend that metabolic syndrome is generally characterized by a collection of 3 or more specified abnormal physiological or biochemical measurements, which can include elevated waist circumference, raised blood pressure, raised fasting glucose, hypertriglyceridemia, and reduced HDL cholesterol.

The relationship between sugars consumption and indicators of metabolic syndrome in individuals is a current debate among health professionals. Most recently, the recommendations made to update the Dietary Guidelines for Americans-2010 (USDA & HHS, 2010) stated: "*Limited evidence shows that intake of sugar-sweetened beverages is linked to higher energy intake in adults*". "*Added sugars, as found in sugar-sweetened beverages (SSB), are not different than other extra calories in the diet for energy intake and body weight*". The effect of individual dietary sugars on health endpoints has been unclear because of a lack of detailed sugar composition data. This impacts interpretation of both prospective studies using free-living subjects as well as retrospective population studies. The Dietary Guidelines recommendation report notes this difficulty: "*Sugar is a ubiquitous term, but one that is not easy to define and measure. Analytical methods can measure total sugar in foods and nutrient databases and Nutrition Facts labels include values for total*

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doi:10.1016/j.fct.2011.07.068

*sugars. Added sugars are typically calculated values and can be added to dietary assessment tools in nutrition studies. As described by Ruxton et al. (2010), exact definitions of sugar are often omitted from studies, making it difficult to determine exactly what was under investigation*" (USDA & HHS, 2010).

Because of the wide distribution of fructose and other individual sugars in foods and limitations in the available data describing its content in the majority of food items, it has been difficult to accurately calculate fructose and other sugar intakes for an individual. For added sugar intake, USDA provides the added sugar content in foods, which can be used to calculate an individual's total added sugar intake. However, it cannot be used to distinguish which kinds of added sugars were consumed by the individual. Added sugars mainly include dietary sugar/molasses from beet or cane, corn sweeteners (including HFCS-55, HFCS-42, and corn syrup), honey, maple sugar/syrup, and sorghum syrup. Among these added sugars, fructose contents are different. Previously, Glinsmann et al. (1986) estimated total sugar, fructose, glucose, and other sugar intakes by using conversion factors of defined food groups. This method can be used to estimate mean fructose intake and its variance in a given population but not to estimate fructose intake of an individual.

The objective of this study was to estimate dietary fructose and non-fructose sugar intakes of individuals based on the Food Commodity Intake Database (FCID) (The US Environmental Protection Agency (EPA, 2000), the sugar content of foods reported in the USDA National Nutrient Database for Standard Reference (USDA-ARS, 2008), and dietary intake data from National Health and Nutrition Examination Survey (NHANES) 1999–2006. Further, population intake patterns of fructose and non-fructose sugars were described and related to certain biological measurements, including the indicators of metabolic syndrome. This work provides a picture of population consumption of fructose and non-fructose sugars and the relationships between dietary fructose, non-fructose sugars, and bio-measurements of health for Americans. To our knowledge, this work is the first to describe fructose and non-fructose sugar intake and its correlations with the characteristic indicators of metabolic syndrome in the US population.

## 2. Methods

### 2.1. Subjects and data

Subjects were selected from databases of the US Center for Disease Control (CDC), National Health and Nutrition Examination Survey (NHANES) 1999–2000, NHANES 2001–2002, NHANES 2003–2004, and NHANES 2005–2006 (publically available from http://www.cdc.gov/nchs/nhanes.htm). NHANES is a program of studies designed to assess the health and nutritional status of adults and children in the United States. The study protocol of NHANES was approved by Research Ethics Review Board of CDC National Center for Health Statistics, and documented consent was obtained from participants. In total, 25,506 participants, aged 12–80 yr (teenagers and adults), were included in this analysis. Data of dietary intakes, demographics, certain biological measurements, and related medication uses were extracted from the databases. Each individual's dietary intakes of fructose and non-fructose sugars were calculated. For the subset of the population (adults aged 19–80 yr, $n$ = 17,749), fructose and non-fructose sugars intakes were related to biological indicators used to define metabolic syndrome, including fasting triglyceride (TG), high-density lipoprotein cholesterol (HDLC), glycohemoglobin (HbA1c), blood pressure (BP), and waist circumference (WC). The reason for using HbA1c rather than glucose concentration is that HbA1c can proportionally and more stably reflect blood glucose concentration and be less influenced by non-fasting status (CDC-NHANES, 2007–2008). Beyond the indicators of metabolic syndrome, uric acid (UA) and BMI were also related, because uric acid appearance in blood has been suggested to have a potential link with fructose intake and diabetes (Johnson et al., 2009) and sugar intake is proposed to be linked with obesity. Participants who were taking medications aimed at affecting TG, HDLC, HbA1c, BP, or UA were excluded accordingly when graphically describing these variables. In addition, participants with fasting blood TG concentration over 500 mg/dL (with a range of 501–3780) were also excluded in graphing TG, because those subjects were likely to have severe disorders of lipid metabolism. For the dietary intakes, data that did not meet the criteria of reliable recall status as indicated by the databases were not used.

### 2.2. Estimation of dietary fructose and non-fructose sugar intakes

The intake data of fructose and non-fructose sugars are not reported explicitly in the NHANES 1999–2006 databases. For the current work, we used the method reported by Sun et al (Sun et al., 2010) to calculate fructose intake of individuals. In this method, the Food Commodity Intake Databases (FCID), released by the US Environmental Protection Agency (EPA) in 2000 (The US Environmental Protection Agency (EPA, 2000) and the USDA National Nutrient Database for Standard Reference (SR22) (USDA-ARS, 2008), published on the website of USDA Agricultural Research Service (ARS), were used to document the intrinsic fructose contents for fructose-containing food commodities. From a total of 548 commodities, 135 potentially fructose-containing commodities were identified, and the fructose content data for131 commodities were obtained. Four minor commodities did not have the fructose data (e.g. dry tomatoes, radish tops). Using the commodity fructose content data, Food Commodity Composition Database in FCID, and NHANES food intake databases, naturally occurring unbound fructose intake of each individual was calculated.

Fructose intake from added sugars can also be estimated with this method. The added sugars in this work include dietary sugar and molasses from cane or beet, corn sweeteners (including HFCS-55, HFCS-42, and corn syrup), maple sugar/syrup, honey, and sorghum syrup. These added sugars are listed in the EPA food commodity composition database. Because corn sweeteners include HFCS-55, HFCS-42, and corn-syrup, the fructose content in corn sweeteners was calculated based on corn sweetener disappearance data and the ratio of HFCS-55/HFCS-42/corn-syrup reported by USDA 1999–2006 (USDA, 2008). Unbound fructose contents in molasses/syrup/honey were obtained from the nutrient database SR22. Bound fructose was set at 50% of the sucrose from added sugars. The intakes of added fructose and total fructose for individuals were calculated using the data sets mentioned above. Lastly, based on obtained fructose intake, non-fructose sugar intake was calculated by subtracting total fructose from total sugars.

### 2.3. Statistics

Statistical description was conducted using SAS software (version 9.1, SAS Institute, Cary, N.C.). NHANES 1999–2000 and 2001–2002 have only one-day dietary data, while NHANES 2003–2006 have two-days dietary data. The day-1 data were obtained by in-person interview and the day-2 data by phone-call interview. About 10% subjects lack the day-2 data in NHANES 2003–2006. To maintain consistency between the data sets and have a larger sample size, we used only the day-1 data of the NHANES 2003–2006 datasets (this can potentially lead to an overestimation of intake). The four databases were merged and descriptive statistics were performed. Basic data of subjects which include means of age, BMI and dietary intakes are calculated using SAS Survey-means procedure with adjustment for population weights. Frequency distributions of the ratios of fructose to non-fructose sugar intakes and % kcal (kcal = kilocalorie or 4.184 kJ) from the two kinds of sugars were drawn using SAS Univariate procedure. To describe relationships between sugar intakes and the bio-indicators of metabolic syndrome, UA, and BMI, figures with dual vertical axes were plotted using EXCEL charting tools. Briefly, the adults were assigned into 11 groups based on their fructose and non-fructose sugar intake (% kcal) percentiles of $\leqslant$10th, 20th, 30th, 40th, 50th, 60th, 70th, 80th, 90th, 95th, and >95th. Then, the group means of bio-measurements and corresponding sugar intake weights (g/day) were calculated. Further, the Figs. 4–10 were plotted using primary vertical axis representing bio-measurements, secondary vertical axis representing sugar intakes (g/day), and horizontal axis representing sugar percentile intake (% kcal) levels.

It is known that 1-day consumption data can be less characteristic of an individual's intake compared to 2- or multiple-days data (Dodd et al., 2006). In order to check consistency of the statistical descriptions using 1-day data versus 2-days data, we separately performed each of the analyses using the 2-days intake data of NHANES 2003–2006. Beyond the sample size of the day-2 data being smaller by about 10% compared to the day-1 data of the same data sets, and the sugar intake means of the 2-days data being about 3.2% less than that of the day-1 data, the other outcomes were similar to that of using the day-1 data only. Consequently, we viewed that the results of analyses based on the day-1 data, which utilized more databases (NHANES 1999–2006) and a larger sample size, would not be appreciably different from that using 2-days data.

## 3. Results

### 3.1. Subject characteristics and dietary intakes

In this descriptive analysis, 25,506 participants, aged 12–80 years, were included from the databases of NHANES 1999–2006. The means and medians of age, BMI, and major dietary intakes are presented in the Table 1. About a quarter of daily calorie intake came from total sugars with 21% from added sugars in teenagers and 16% in adults. Among the total sugars, the fructose portion

**Table 1**
Basic data of participants, NHANES 1999–2006, weighted sample sizes.

| | Teenagers, aged 12–18 yr | | | | Adults, aged 19–80 yr | | | |
|---|---|---|---|---|---|---|---|---|
| | Mean | Median | SD | SEM | Mean | Median | SD | SEM |
| | n = 7757 (50.54% males) | | | | n = 17,749 (48.46% males) | | | |
| Age, year | 14.93 | 15 | 2.01 | 0.03 | 43.92 | 44 | 17.97 | 0.13 |
| BMI, kg/m$^2$ | 23.07 | 22.16 | 5.97 | 0.08 | 28.25 | 27.43 | 6.5 | 0.06 |
| Dietary intakes | | | | | | | | |
| Energy, kcal/d | 2309 | 2253 | 1079 | 17.87 | 2254 | 1994 | 1039 | 9.94 |
| Total fat, g/d | 85.24 | 75.5 | 46.99 | 0.77 | 84.75 | 71.69 | 46.84 | 0.45 |
| % kcal/d | 32.73 | 32.83 | 8.19 | 0.13 | 33.41 | 32.95 | 9.22 | 0.09 |
| Carbohydrate, g/d | 308.97 | 274.28 | 149.66 | 2.47 | 275.09 | 246.23 | 136.24 | 1.30 |
| % kcal/d | 54.12 | 54.04 | 10.34 | 0.17 | 49.49 | 50.6 | 11.66 | 0.11 |
| Total sugars, g/d | 158.64 | 136.33 | 92.35 | 1.53 | 129.65 | 109.48 | 85.99 | 0.86 |
| % kcal/d | 27.83 | 26.75 | 10.71 | 0.18 | 23.16 | 22.62 | 11.06 | 0.11 |
| Added sugars, g/d | 120.33 | 99.73 | 85.21 | 1.45 | 92.54 | 68.67 | 81.1 | 0.83 |
| % kcal/d | 21.02 | 19.5 | 11.44 | 0.19 | 16.04 | 14.05 | 11.44 | 0.11 |
| All fructose, g/d | 58.85 | 50.19 | 38.25 | 0.63 | 48.07 | 39.16 | 35.73 | 0.36 |
| % kcal/d | 10.33 | 9.84 | 4.79 | 0.08 | 8.53 | 8.07 | 4.82 | 0.05 |
| Non-fru sugars, g/d | 99.79 | 85.27 | 58.06 | 0.97 | 81.59 | 69.42 | 53.76 | 0.53 |
| % kcal/d | 17.51 | 16.8 | 6.82 | 0.11 | 14.63 | 14.36 | 7.06 | 0.07 |

SD/SEM, standard deviation/error of mean; kcal, kilocalorie or 4.184 kJ; Non-fru, non-fructose.

represented about 37%, and the rest were non-fructose sugars mainly contributed by glucose and lactose. Figs. 1 and 2 show the participant's distribution data for the ratio of dietary fructose to non-fructose sugar intakes in g/day and fructose % kcal/day accordingly. The ratio and fructose % kcal data appeared very similar between all participants and adults. The median, 95th, and 99th percentile values for the ratio data of fructose to other sugars are 0.589, 0.92 and 1.197 (Fig. 1A) in all participants, which means that up to 95% of the participants did not report a one day food intake with a fructose to non-fructose sugar ratio over 0.92. The corresponding data for adults are 0.584, 0.921, and 1.197 (Fig. 1B), respectively. The median, 95th, and 99th percentile values of % kcal from fructose are 8.651%, 17.78%, and 22.82% (Fig. 2A) in all participants, respectively, which indicates that up to 95% of the participants did not report a one day food intake with fructose energy over 17.78%. The corresponding data in adults are 8.07%, 17.32%, and 22.56% (Fig. 2B), respectively.

### *3.2. Relations among fructose intake, non-fructose sugar intake, and bio-measurements*

In the adult population, the relations among fructose intake, non-fructose sugar intake and indicators of metabolic syndrome, uric acid and BMI were depicted in Figs. 3–10. Fig. 3 displays the detailed intake pattern between fructose and non-fructose sugars. The *x*-axis shows 12 fructose intake levels by % kcal (from $\leqslant$2% to >22%), the *y*-axis shows 12 non-fructose sugar intake levels by % kcal (from $\leqslant$4% to >24%), and the *z*-axis displays numbers of subjects (frequencies, ranged from 0 to 671) of corresponding groups determined by interactions of the two kinds of sugar intake levels. In the left-front area as circled, the sample sizes of each intake group are very small (0–3), while the majority of subjects are located in the right side central area (center diagonal from the origin low–low intake to the high-high intake of fructose and non-fructose sugars). The distribution attribute indicates that it was less likely for an individual to have a higher fructose intake without a correspondingly higher non-fructose sugar intake. The peak area of the plot also demonstrates that, for the majority of the population studied, whether sugar intakes (% kcal/day) were lower or higher, the ratios of fructose to non-fructose sugars were held in a fairly narrow range. Consumption of fructose or non-fructose sugar alone as dominant sugar was uncommon in the typical American diet.

To describe the relationships between the sugar intakes and the bio-measurements, the mean data of sugar intakes and bio-measurements by sugar intake (% kcal) percentile groups were plotted in Figs. 4–10. Fig. 4 shows the relations of serum TG concentrations (fasting samples, $n = 8065$) and the two kinds of sugar intakes in % kcal and g/day. With respect to increasing fructose and non-fructose sugar intakes, the TG concentration means fluctuates between 130 and 140 mg/dL with no significant trend noted. The intake data in % kcal of the sugars are closely correlated to the intake data in g/day. Within a same percentile intake group, non-fructose sugar intake amount is always higher than that of fructose. For the lowest % kcal intake group ($\leqslant$10 percentile), the non-fructose intake mean is 23.9 g/day and the fructose value is 10.0 g/day, and the data are 148.0 and 104.7 g/day, respectively, for the highest percentile intake group (<95 percentile). Figs. 5–10 demonstrate the relationships among the data of HDLC, BP, HbA1c, WC, UA, BMI, fructose and non-fructose intakes. With increasing sugar intakes, either as % kcal or g/day, it appears that all the bio-measurement mean data are relatively flat or decrease with significant trends and small negative $\beta$ values. More obvious decreases of HDLC and uric acid data can be seen with intake increases of both fructose and non-fructose sugars. The data lines in the figures of WC and BMI are almost visually identical.

## 4. Discussion

This work has described fructose and other sugars consumption of individuals based on their one-day food intakes in the NHANES 1999–2006 databases and these data were grouped and then related to certain health indicators. In this way, a more precise description is provided of the relationships between intakes of fructose and the other sugars, and between the sugar intakes and the health indicators.

Fructose at 37% of the total sugars consumed is not the majority sugar in the diet. High fructose corn syrup in foods has replaced about half of the dietary sucrose over the last 40 years (USDA-ERS, 2010). Since both sugar products contain an approximate 1 to 1 ratio of fructose to glucose, the fructose to glucose ratio from added sugars has not significantly changed over this time period. The data in this study is consistent with the earlier data generated by Park (Park and Yetley, 1993) showing a ratio of 0.40–0.43 of dietary fructose to glucose and the data by Glinsmann showing an approx-

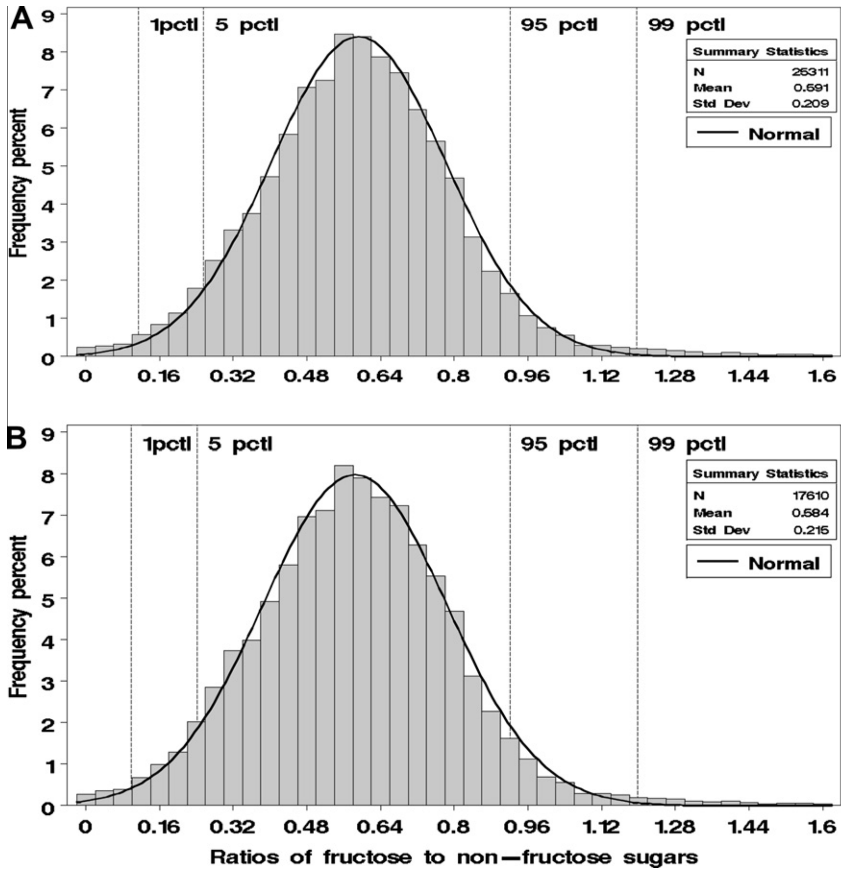


**Fig. 1.** Distribution of ratios of dietary fructose to non-fructose sugars (w/w). (A) all subjects ($n$ = 25,506), aged 12–80 yr; (B) adults ($n$ = 17,749), aged 19–80 yr; pctl = percentile. The data of ratios > 1.6 are not shown in the plot. The bell curves are normal distribution fittings.

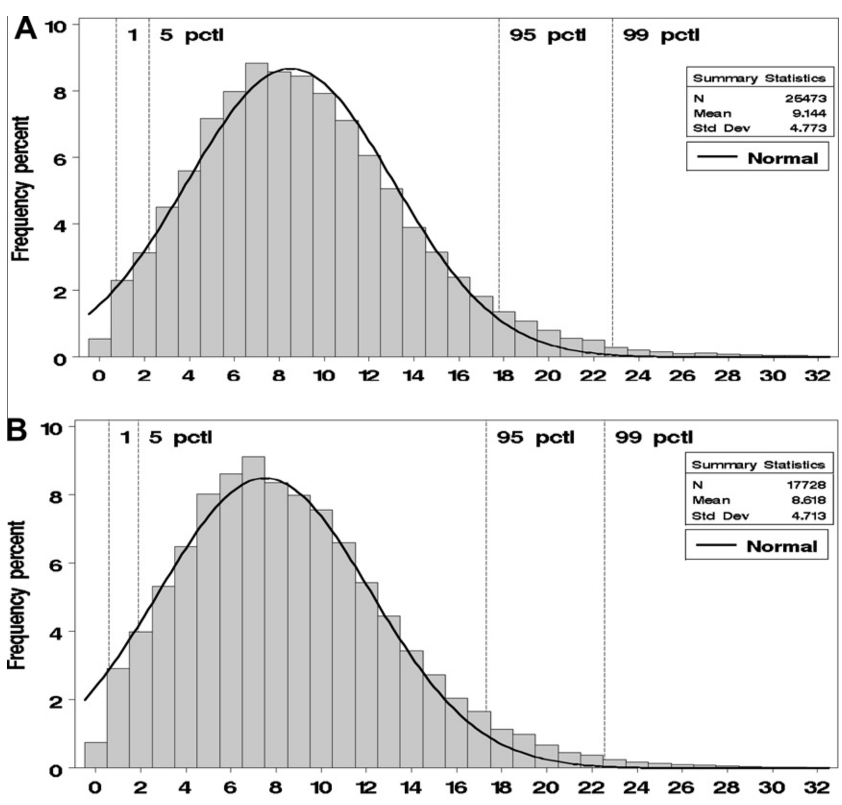


**Fig. 2.** Distribution of dietary fructose intake (% kcal/day). (A) All subjects ($n$ = 25,506), aged 12–80 yr; (B) adults, aged 19–80 yr ($n$ = 17,749); kcal = kilocalorie or 4.184 kJ; pctl = percentile. The data of % kcal > 32 are not shown in the plot. The bell curves are normal distribution fittings.

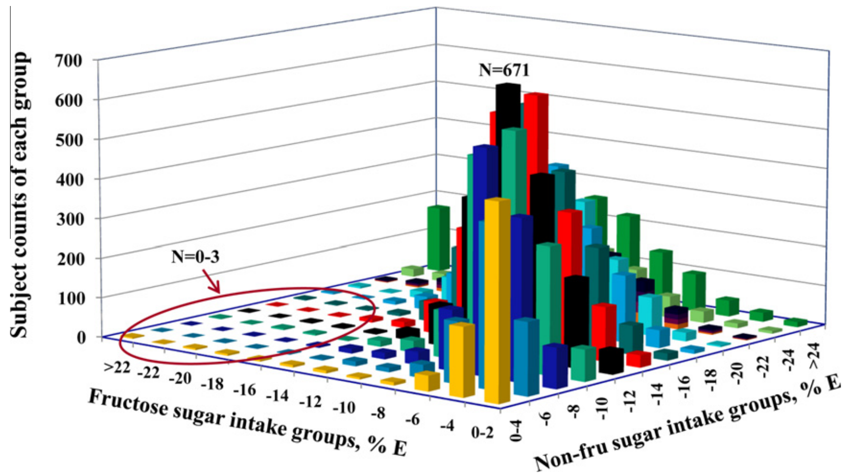


**Fig. 3.** Sample size distribution by interaction of fructose intake and non-fructose intake (% kcal) in adults ($n$ = 17,749). $X$-axis = fructose % Energy (% kcal), $y$-axis = non-fructose sugars % Energy (% kcal), and $Z$-axis = subject frequency (counts from 0 to 671). The distribution attribute indicates that fructose generally contributed less daily calorie than non-fructose sugars, the ratios of fructose to non-fructose sugars were held in a fairly narrow range and consumption of fructose or non-fructose sugar alone as dominant sugar was uncommon in the typical American diet. For example, in the left-front area as circled, the frequencies of participants who had higher fructose intakes without allied high non-fructose sugar intakes are very low (0–3 counts for many cells).

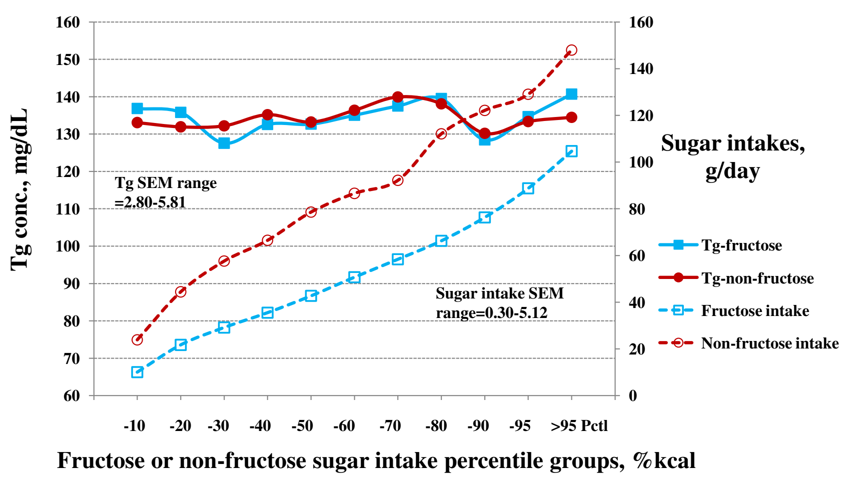


**Fig. 4.** Relations of serum TG concentration and fructose/non-fructose sugar intakes (% kcal or g/day) in adults, fasting blood samples, $n$ = 8065. Solid squares and line (Tg-fructose) represents the data of TG concentration against fructose intake in % kcal and g/day. Solid circle and line (Tg-non-fructose) represents the data of TG concentration against non-fructose sugar intake in % kcal and g/day. Empty squares and circles and broken lines represent fructose and non-fructose sugar intakes (% kcal and g/day), respectively. SEM = standard error of mean. No significant trend was noted between the data of TG concentration and sugar intakes.

imate 38.9% fructose content of total dietary sugars (Glinsmann and Park, 1995).

The amounts of fructose reported in the individual food intake data rarely exceeded 23% (99th percentile) of daily dietary kilocalories, and fructose mean consumption approximated 9% kcal for adults aged 19–80 yr and 10.4% for teenagers aged 12–18 yr. For more than 97% of the individuals studied, the intake of fructose was less than the intake amount of the other sugars. The ratio of consumed sugars by the majority of the individuals ranged from 0.3–0.9 to 1 of fructose to non-fructose sugars, regardless of total sugar intake. Dietary fructose, non-fructose sugars, added sugars, total sugars, and total carbohydrates are all closely correlated one to another ($r$ = 0.71 to 0.95, all $P$ < 0.0001), by both Pearson and Spearman correlations (detailed data not shown). The close correlations would indicate that it is difficult to clearly interpret a significant association between a single sugar intake and a health-related outcome before clearly distinguishing the multi-colinearity of different carbohydrates in diet.

The results presented (Figs. 1–3) describe the distributions of fructose intake and fructose to non-fructose sugar ratio in the diets. The graphic responses of sugar intakes plotted against the bio-measurements, depicted in Figs. 4–10, indicate a lack of positive association. Although negatively significant correlations are noted between fructose/non-fructose sugar intakes and the bio-measurements (except TG concentration), considering the small correlation coefficients and many other factors linked with the correlated variables, the negative trends from simple correlations may not be important. One-day or 2-days dietary data from an individual can not be assumed to be predictive of long term consumption patterns for that person, but can be used to estimate population means and variance of intakes. Thus, the data are valuable because they provide estimates of distributions and ranges in population intakes for fructose and other sugars. These distributions serve as a reference for interpreting outcomes of studies testing individual sugars alone and using sugar dosages that exceed the 95th percentile of population intakes.

Metabolic interactions can exist between the various sugars, such as that found between fructose and glucose, and it is clear that fructose ingested alone can behave differently from that consumed together with glucose. For example, fructose intolerance oc-

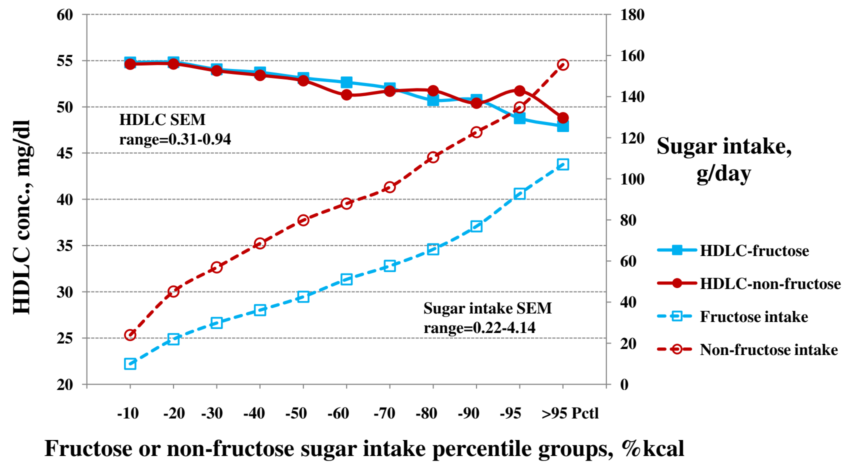


**Fig. 5.** Relations of serum HDLC concentration and fructose/non-fructose sugar intakes (% kcal or g/day) in adults, $n = 17{,}659$. Solid squares and line (HDLC-fructose) represents the data of HDLC concentration against fructose intake in % kcal and g/day. Solid circle and line (HDLC-non-fructose) represents the data of HDLC concentration against non-fructose sugar intake in % kcal and g/day. Empty squares and circles and broken lines represent fructose and non-fructose sugar intakes (% kcal and g/day), respectively. SEM = standard error of mean. Significant trends ($P < 0.05$) were noted between the data of HDLC concentration and sugar intakes.

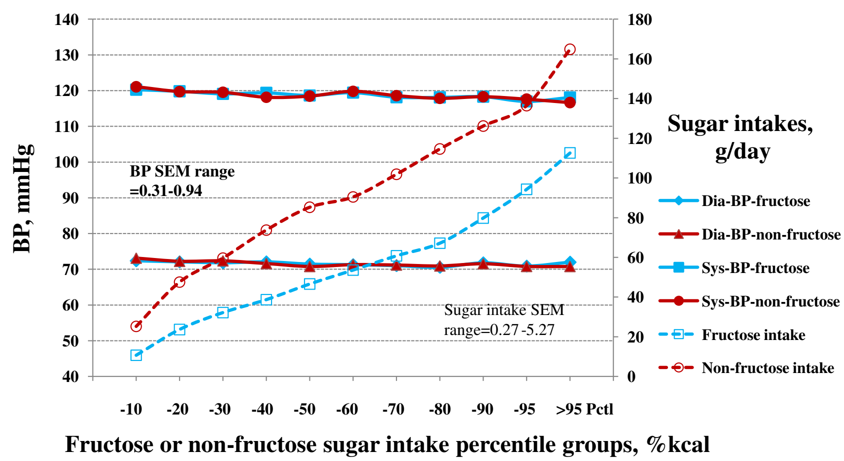


**Fig. 6.** Relations of blood pressure (BP) and fructose/non-fructose sugar intakes (% kcal or g/day) in adults, $n = 13{,}001$. Solid squares and line (Sys-BP-fructose) represents the data of systolic blood pressure against fructose intake in % kcal and g/day. Solid circles and line (Sys-BP-non-fructose) represents the data of systolic blood pressure against non-fructose sugar intake in % kcal and g/day. Solid diamonds and line (Dia-BP-fructose) represents the data of diastolic blood pressure against fructose intake in % kcal and g/day. Solid triangles and line (Dia-BP-non-fructose) represents the data of diastolic blood pressure against non-fructose sugar intake in % kcal and g/day. Empty squares and circles and broken lines represent fructose and non-fructose sugar intakes (% kcal and g/day), respectively. SEM = standard error of mean. Significant trends ($P < 0.05$) were noted between the data of both BP and sugar intakes.

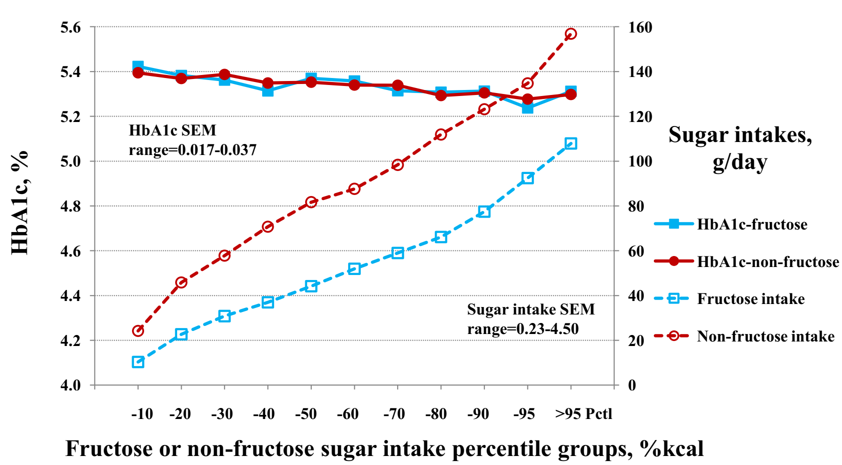


**Fig. 7.** Relations of blood HbA1c concentration and fructose/non-fructose sugar intakes (% kcal or g/day) in adults, $n = 16{,}629$. Solid squares and line (HbA1c-fructose) represents the data of HbA1c concentration against fructose intake in % kcal and g/day. Solid circle and line (HbA1c-non-fructose) represents the data of HbA1c concentration against non-fructose sugar intake in % kcal and g/day. Empty squares and circles and broken lines represent fructose and non-fructose sugar intakes (% kcal and g/day), respectively. SEM = standard error of mean. Significant trends ($P < 0.05$) were noted between the data of HbA1c concentration and sugar intakes.

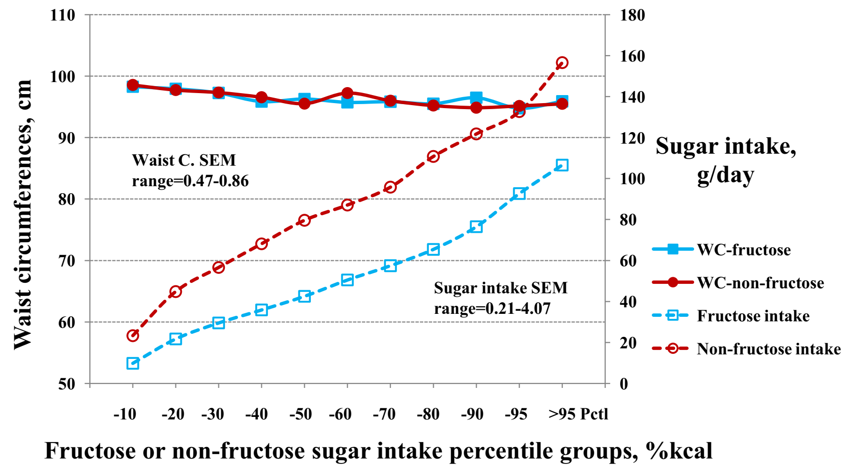


**Fig. 8.** Relations of waist circumferences (WC) and fructose/non-fructose sugar intakes (% kcal or g/day) in adults, $n = 17{,}749$. Solid squares and line (WC-fructose) represents the data of WC against fructose intake in % kcal and g/day. Solid circle and line (WC-non-fructose) represents the data of WC against non-fructose sugar intake in % kcal and g/day. Empty squares and circles and broken lines represent fructose and non-fructose sugar intakes (% kcal and g/day), respectively. SEM = standard error of mean. Significant trends ($P < 0.05$) were noted between the data of WC and sugar intakes.

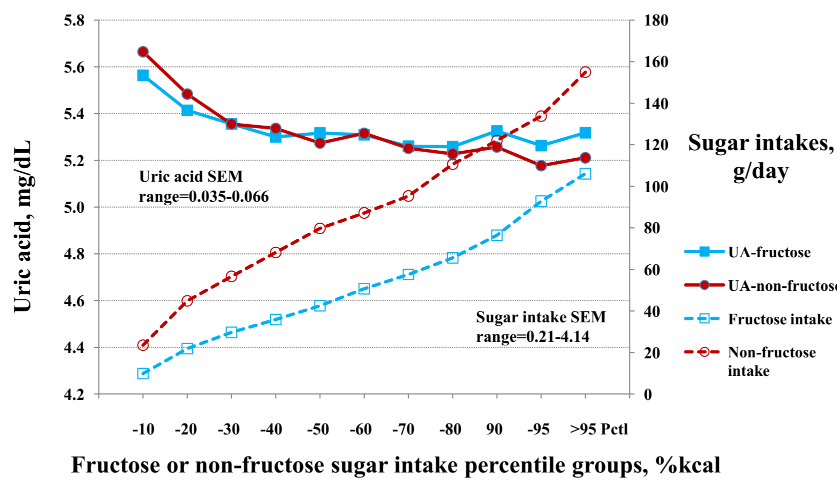


**Fig. 9.** Relations of serum uric acid (UA) concentration and fructose/non-fructose sugar intakes (% kcal or g/day) in adults, $n = 17{,}661$. Solid squares and line (UA-fructose) represents the data of uric acid concentration against fructose intake in % kcal and g/day. Solid circle and line (UA-non-fructose) represents the data of uric acid concentration against non-fructose sugar intake in % kcal and g/day. Empty squares and circles and broken lines represent fructose and non-fructose sugar intakes (% kcal and g/day), respectively. SEM = standard error of mean. Significant trends ($P < 0.05$) were noted between the data of UA concentration and sugar intakes.

curs when it is consumed alone, but intolerance symptoms disappear when glucose is present (Riby et al., 1993). Others have shown that fructose consumed alone contributes little to glycogen synthesis, while fructose consumed with glucose is a significant contributor to glycogen synthesis (Coss-Bu et al., 2009). The sugar interactions, together with the observation that most Americans appear to consume mixed sugars in their daily meals, are important considerations when extrapolating study outcomes to metabolic consequences of sugars in the ordinary diet.

Furthermore, to be valid, the consequences of sugar consumption on health parameters should be investigated based on ranges of usual intake in the population. In traditional food safety studies, upper intake levels used to assess adverse effects are typically those associated with the 90th percentile of consumers (FDA Guidance, 2008), and more recently the 95th percentile has sometimes been used. Consequently, the utility and significance of conducting studies at dosages higher than the 90th or 95th percentile is inconsistent with the principles applied to safety studies. In the case of fructose, studies using fructose doses at or above 17.8% of energy (95th percentile) would exceed the FDA guidance level of food safety studies. The data presented in this report, based on one-day food intake data, likely provides an overestimate of the range and means of sugar intakes.

This work has several limitations. NHANES food intake data are a snapshot of one- or two-days recalls. Thus, the intake data may not represent long term, consistent consumption amounts for a food or nutrient. Together with the retrospective feature of the data, the noted flat or negatively correlated relations between sugar intakes and bio-measurements should not be used to conclude an effect or non-effect, they are direct descriptions of the data. Secondly, due to no fructose intake data being available in NHANES databases and a lack of fructose content data for many food items in the USDA National Nutrient Database for Standard Reference, the fructose intake of individuals was indirectly estimated using several databases together as described in the Methods section. Extra error could be induced. However, the accuracy of this estimation has been reported previously (Sun et al., 2010) and would be accurate enough for the purpose of the current work of estimating fructose intake distribution and contribution to total sugars in the diet.

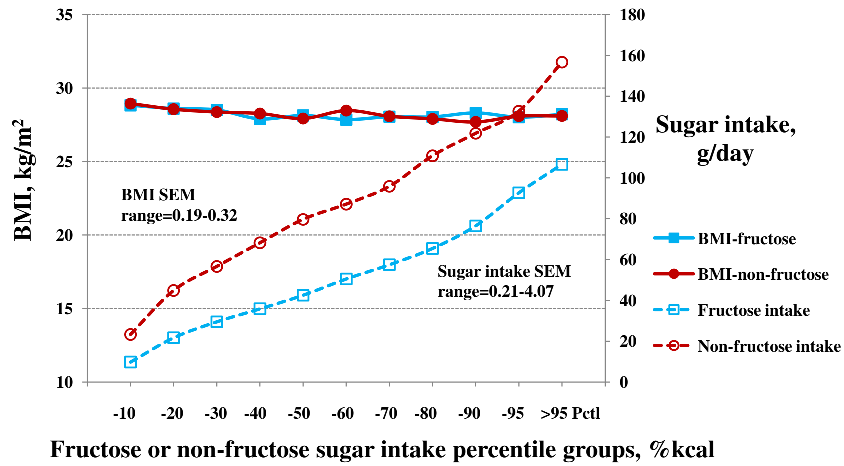


**Fig. 10.** Relations of BMI and fructose/non-fructose sugar intakes (% kcal or g/day) in adults, *n* = 17,749. Solid squares and line (BMI-fructose) represents the data of BMI against fructose intake in % kcal and g/day. Solid circle and line (BMI-non-fructose) represents the data of BMI against non-fructose sugar intake in % kcal and g/day. Empty squares and circles and broken lines represent fructose and non-fructose sugar intakes (% kcal and g/day), respectively. SEM = standard error of mean. Significant trends ($P < 0.05$) were noted between the data of BMI and sugar intakes.

In conclusion, fructose content in the typical American diet was usually less than non-fructose sugars, averaging approximately 37% of total dietary sugars. Fructose and non-fructose sugar consumptions at levels representative of the American diet were not positively associated with indicators of the metabolic syndrome. Clinical studies designed to assess associations among fructose intake representative of the American diet and these metabolic parameters would be informative.


## Funding source

The funding for this work was provided by Archer Daniels Midland Company.


## Conflict of Interest

The authors, except GH Anderson, are employed by Archer Daniels Midland Company.

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