The Sweetening of the World's Diet

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Abstract

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Objective: Using data from many countries in the world combined with in-depth U.S. dietary data, we explored trends in caloric sweetener intake, the role of urbanization and income changes in explaining these trends, and the contribution of specific foods to these changes.

Research Methods and Procedures: Food disappearance data from 103 countries in 1962 and 127 in 2000 were coupled with urbanization and gross national income per capita data in pooled regression analysis to examine associations between these factors and caloric sweetener intake. Three nationally representative surveys from 1977 to 1978, 1989 to 1991, and 1994 to 1996 plus 1998 are used to examine caloric sweetener intake trends in the United States and the foods responsible for these changes.

Results: Increased consumption of caloric sweetener is one element in the world's dietary changes, represented by a 74-kcal/d increase between 1962 and 2000. Urbanization and income growth represent 82% of the change. U.S. data show an 83-kcal/d increase of caloric sweetener consumed—a 22% increase in the proportion of energy from caloric sweetener. Of this increase, 80% comes from sugared beverages; restaurant and fast food sources are represented in greater proportions.

Discussion: Caloric sweetener use has increased considerably around the world. Beverage intake seems to be a major contributor.

Key words: caloric sweetener, dietary trends, urbanization, soft drink intake

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Introduction

After World War II, the world's diet shifted markedly. One critical change, noted often in the United States but not clearly examined around the world, is the increase in consumption of caloric sweetener. Whereas there are other equally important changes, namely in edible oil and animal source food intake, this paper focuses on caloric sweeteners (1,2).

The increase in consumption of soft drinks and sugared fruit drinks is a critical element in the shift in diet (3–5). Many people in the food industry have argued that all calories are equal and that caloric sweetener has no important health implications. The soft drink industry and a series of conferences by a food industry–sponsored foundation have further claimed that one calorie from any refined or other carbohydrate is equivalent to another and that shifts in caloric sweetener intake should not be of major concern (6). In the past there has been little evidence to counter these assertions. Recently, several health concerns have been consistently voiced. First, the high consumption of sugar-sweetened beverages has been linked with increased energy intake and obesity (5,7). Second, cancer researchers have voiced concerns over the reduced intake of more complex carbohydrates and high-fiber foods and replacement of these food sources with refined carbohydrates (8). Third, milk has been increasingly substituted with soft drinks (4,9). A careful long-term blinded ad libitum supplementation study found that overweight subjects who consumed large amounts of caloric-sweetened beverages increased energy intake, body weight, fat mass, and blood pressure after a 10-week intervention. This was not observed in a similar group receiving artificial sweeteners (10). Calories from fluids are less sating than those from solid foods and often lead to overconsumption (11) (Bray et al., unpublished observations).

This study does not attempt to review and establish the importance of caloric sweetener as a causal mechanism for obesity or other chronic diseases. Rather, we focus on examining the shifts in caloric sweetener consumption and presence in the world's food supply.

Sugar is the world's predominant sweetener. It is not clear exactly when sugar became the world's principal sweetener—most likely in the 17th or 18th century as the

New World began producing large quantities of sugar at reduced prices (12,13). Sugar use has since been linked with industrialization and with the proliferation of processed foods and beverages that have sugar added to them (e.g., tea, coffee, cocoa).

The standard definition used by researchers (which was used for the U.S. analyses) for caloric sweeteners includes all caloric carbohydrate sweeteners and excludes all naturally occurring sugars (which represent an important component of our energy intake). Several cross-sectional studies show that caloric sweeteners play a very large role in the U.S. diet, approximating 16% of energy for some subpopulation groups (4,9,14,15).

This paper's first component uses cross-country analysis, based on food disappearance data from around the world, to examine the trends in caloric sweetener intake between 1962 and 2000. The analysis is supplemented with detailed, nationally representative, individual dietary intake data from the United States between 1977 and 1998. These data show the trends by location and food source of the caloric sweetener use in a country with very good food composition data.

Research Methods and Procedures

Ecological Analysis

Current measurements of the total food available for human consumption are similar to food disappearance data between 1962 and 2000 from the Food and Agricultural Organization of the United Nations. Food available for consumption is calculated by adding total food production (plus imports, minus exports) and net losses from processing at the mill level and food fed to animals. These data are a reasonable approximation in all countries of the trends in food consumption (use) at the national level. The data do not reflect actual consumption, however, because additional losses in the food chain linking the producers and mills to the consumers are not considered. Scholars who have compared food disappearance data with household and individual food intake data often estimate that disappearance data measure ~20–27% more food available for consumption than is evidenced by the actual consumption levels. However, there is little research to enable identification of the actual level for each country (16).

In addition, compared with nonperishable foods, a greater proportion of perishable foods is lost, wasted, and/or discarded between production and consumption. For example, food disappearance data overestimate the amount of fruits and vegetables available for consumption relative to grains and tubers. Assumptions about the degree of food extraction and perishability have not necessarily been correctly adjusted over time. Given the continual improvements in storage and distribution of food—particularly for more perishable fruits and vegetables—underestimation of intake might be more prevalent today than it was two decades ago. For foodstuffs with added sugar, we expect to see a much more limited problem with wastage.

Caloric Sweetener Definition–Sugar Crops, Sweeteners, and Derived Products

For the entire study we use the term caloric sweetener instead of added sugar because there is such a range of nonsugar products used today. High fructose corn syrup is a prime example because it is the sweetener used in all U.S. soft drinks. There are two major sugar crops: sugar beets and sugar cane. Sugar and syrups are also produced from the sap of certain species of maple trees, from sweet sorghum when cultivated explicitly for making syrup, and from sugar palm. Under the name sweeteners, the Food and Agricultural Organization includes products used for sweetening that are either derived from sugar crops, cereals, fruits, or milk, or produced by insects. This category includes a wide variety of monosaccharides (glucose and fructose) and disaccharides (sucrose and saccharose), which exist either in a crystallized state as sugar or in thick liquid form as syrups. Included in sweeteners are maple sugar and syrups, caramel, golden syrup, artificial and natural honey, maltose, glucose, dextrose, isoglucose (also known as high fructose corn syrup), other types of fructose, sugar confectionery, and lactose. In the last several decades, increasingly larger quantities of cereals (primarily maize) have been used to produce sweeteners derived from starch.

Urbanization. We obtained the percent urbanization of each country for each year used in this study from the Food and Agricultural Organization of the United Nations database. Their data are obtained from the United Nations Population Division.

Gross National Product per Capita. For the national food consumption and economic pattern analysis, we expressed the gross national product (GNP)[1] per capita in 1995 dollars to enable easier comparison of results. We obtained these data from the World Development Indicator 2002 CD-ROM, prepared by the World Bank (Washington DC). Most of the statistics in the World Development Indicators are data from national statistical agencies.

Methods. The sample comes from the identical countries in 1962 and 2000; however, by 2000, the Soviet Union had separated into individual countries. Therefore, the sample used is 103 countries in 1962 and 127 in 2000. Regression analyses were used to relate dietary data (the absolute level of caloric sweetener and proportion of energy and carbohydrate from added caloric sweeteners) to the logarithm of per capita GNP and the proportion of the country that is urban.

[1] Nonstandard abbreviations: GNP, gross national product; USDA, United States Department of Agriculture; CSFII, Continuing Survey of Food Intake by Individuals; RTE, ready to eat.

The samples of 103 and 127 countries were combined for this analysis.

In the regression analyses, we regressed the following: 1) the caloric sweetener measures on a polynomial function (GNP, GNP squared, and GNP cubed); 2) the proportion of the population residing in urban areas; and 3) interaction terms between GNP per capita and the proportion of the population residing in urban areas in a given year. This set of three GNP measures captures the complex relationships of GNP with sugar intake. We pooled (combined) the 1962 and 2000 data with added time interactions for all variables. The two groupings of variables that were statistically significant included 1) the GNP variable and its interactions with time and with urbanization and 2) the overall urbanization effect (urban alone and with the full set of GNP and time interactions). We subsequently used simulation techniques used often in demography and economics to apportion the variance explained among changes in the level of GNP per capita and urbanization (called changes in composition) and changes in the behavior of these factors explained by other unmeasured factors. Two papers by Popkin et al. (17,18) use and explain this method further.

Individual Dietary Intake Analysis for the United States

U.S. Dietary Intake Data. The initial sample contained more than 63,380 individuals participating in three U.S. Department of Agriculture (USDA) surveys—all of which were self-weighting, multistage samples of the U.S. population. From this sample, we selected all persons 2 years of age and older with dietary data: 29,695 from the 1977 to 1978 Nationwide Food Consumption Surveys, 14,658 from the 1989 to 1991 Continuing Survey of Food Intake by Individuals (CSFII91), and 19,027 from the 1994 to 1996 CSFII (plus the 1998 child supplement CSFII). These USDA surveys contain stratified area probability samples of noninstitutionalized U.S. households in the 48 coterminous states, collected in each season (19). For each survey, response rates differed at the level of the primary sampling unit. Thus, we use weights based on response rates for each sample unit to permit inferences applicable to the total noninstitutionalized U.S. population (19–21).

For each survey we used all days of 24-hour recall and record. We used the 1994 USDA Nutrient Database to calculate nutrient values from the food intake data in each period. First, we used a food code linking program to assign the same code to comparable foods in each period. Next, we applied values from the 1994 Nutrient Database to the three datasets to provide consistently high-quality estimates of nutrient composition over time. Studies show that using a 1990s Nutrient Database to create macronutrient values for earlier periods made the datasets more comparable without introducing artificial differences in food energy and fat values (22,23).

To examine the thousands of foods contributing to energy intake, we used the University of North Carolina-Chapel Hill food grouping system. This system aggregates all the foods in the USDA nutrient composition tables into 74 descriptive and nutrient-based subgroups. We chose a select few of these subgroups (those that contained most of the caloric sweetener) based on preliminary analysis: desserts (both low and high fat), candy, soft drinks, fruit drinks, low-fiber fruits/noncitrus fruit juices, ready-to-eat (RTE) cereals (low fiber and high fiber), breads, sugar/jellies (note that this group includes toppings and syrups), coffee/tea, and milk and cream products. These foods were chosen after examining all the food groups (including mixed dishes) for the largest contributors to caloric sweetener intake. Although mixed dishes may be consumed in large quantities, they are not large contributors to caloric sweetener intake; rather, they are large contributors to fat intake. The individual food entries represent a large number of foods and food codes from the food table.

Caloric Sweetener Measure. As described by Welsh et al. (24), we developed a category for caloric sweetener to capture all caloric carbohydrate sweeteners (monosaccharides, disaccharides, and higher saccharides), excluding all naturally occurring sugars (such as fructose in fruits), and including all other sugars and sugar-containing ingredients added during processing or preparation. We also included sugars eaten separately (candy) or added at the table (e.g., syrups, white sugar, brown sugar) (24). In accordance with this definition, the USDA included the caloric sweetener variable in the *Pyramid Servings* dataset of the CSFII.

Design Effects, Weights, and Statistical Issues. To test for statistical differences, SAS 8.1 (SAS Institute Inc., Cary, NC) and SUDAAN 7.5.6 (Research Triangle Institute, Research Triangle Park, NC) software packages were used, which also allowed for weights and control of sample design effects. A p value of 0.01 was used to denote statistical significance.

Results

World Trends in Availability

The overall trends in the availability of sugar for the world show a large increase in caloric sweetener available for consumption (Table 1). In 2000, there were 74 more kilocalories per capita of caloric sweetener consumed than in 1962. The percentage of calories from caloric sweetener increased considerably (32% increase or an additional 1.4 percentage points in the percent of energy from caloric sweeteners) and represents a 21% increase in the proportion of carbohydrates that is refined sugar.

We explored the factors associated with these changes. Table 1 provides data for each set of countries for GNP quintiles based on 1962 GNP per capita levels. As GNP per capita of the country increases, all measures of ca-

Table 1. World trends in caloric sweetener intake for GNP quintiles (1962 values)

	Quintile 1	Quintile 2	Quintile 3	Quintile 4	Quintile 5	Total
Caloric sweetener (kcal/capita/day)						
1962	90	131	257	287	402	232
2000	155	203	362	397	418	306
Total carbohydrates (kcal/capita/day)						
1962	1464	1552	1542	1627	1,677	1572
2000	1690	1670	1752	1779	1,693	1717
Total energy (kcal/capita/day)						
1962	2008	2090	2157	2411	2,960	2322
2000	2346	2357	2716	2950	3,281	2725
Percent caloric sweetener of total energy						
1962	4.5	6.2	11.9	12.0	13.5	9.5
2000	6.4	8.3	13.4	13.7	12.7	10.9
Percent caloric sweetener of total carbohydrates						
1962	6.2	8.5	16.8	17.7	24.4	14.6
2000	9.0	12.1	20.6	22.4	24.6	17.7
GNP						
1962	216	478	983	2817	12,234	3282
2000	435	839	2836	5915	28,142	7198
Percent urban						
1962	10.0	21.6	37.3	46.7	66.2	36.1
2000	27.7	41.3	58.7	70.0	78.0	54.9

Source: Food and Agriculture Organization FAOSTAT data set for food balance data.

loric sweetener increase significantly. As shown in Figure 1, between 1962 and 2000, the caloric intake of sugar increased considerably more for the lower- and middle-income countries than for the highest-income countries.

We used the pooled 1962 and 2000 regressions to determine the degree to which income and urbanization measures explained these trends and to find out whether there was any change over time in the effects of these factors that could be attributed to either industrialization or consumer behavior. We found that ~82% of the change in caloric sweetener intake can be attributed to GNP and urbanization changes and the remaining 18% to changes in unmeasured factors, which would relate either to shifts in the behavior of the food industry and/or consumer behavior.

U.S. Patterns and Trends in Caloric Sweetener Intake

In the United States, between 1977 and 1996, urbanization increased from 74% to 76%, while GNP per capita went from ~19,930 to 28,350. During this time, there was a remarkable increase of 83 kcal of caloric sweetener consumed per day for all persons in the United States 2 years of age and older (Table 2). The percentage of energy from caloric sweetener also rose from 13.1 to 16.0 during this period (22%). Between 1994 and 1996, the level of caloric sweetener as a proportion of carbohydrate was very high; more than 30% of carbohydrates came from caloric sweetener.

Table 2 also presents trends by location of consumption activity. Restaurant and fast food sources represent a significant increase of 34 kcal/d, or just over 40% of the total increase. Following procedures used in other studies on this topic, we explored (data not shown) these same trends for meals and snacks (15). One-half of the increase in caloric sweetener in the United States comes from snacks, an element of the diet representing <20% of total energy intake.

Table 3 shows additional information about the food sources of these changes. Of the total increase of 83 kcal, 54 kcal/d come from soft drinks, and 13 kcal come from similar sugared fruit drinks. These figures represent close to 81% of the increase in caloric sweetener intake between 1977 and 1996 for the average U.S. resident 2 years of age and older. Much smaller components of the changes come from desserts (5 kcal) and candy (9 kcal). Figure 2 shows the shifts in caloric sweetener intake from the key food groups (i.e.,

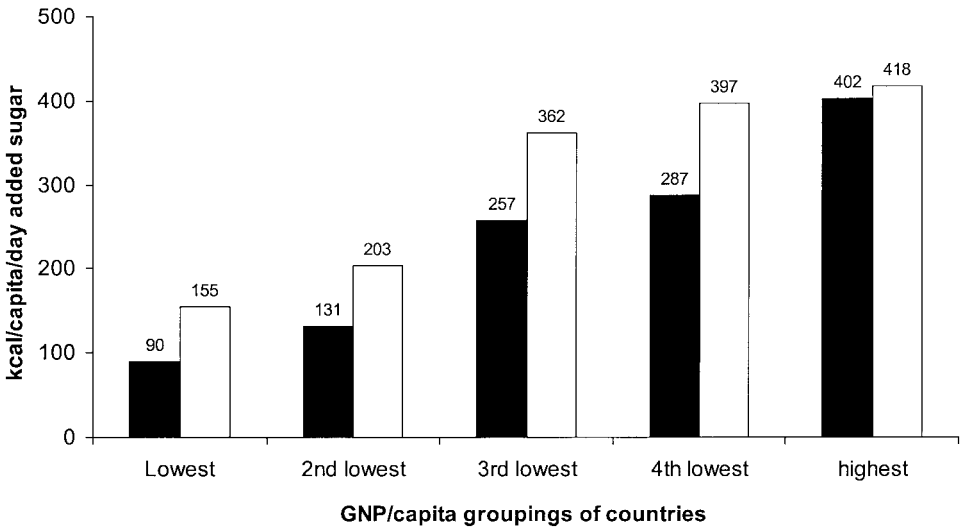

Figure 1: The relationship between changes in GNP per capita and caloric sweetener. Solid bars, 1962; and open bars, 2000.

soft drinks, fruit drinks, desserts, sugar and jellies, candy, and RTE cereals).

Discussion

In this paper, we document the enormous worldwide increase in caloric sweetener to the diet. We show that as income per capita and the proportion of the population residing in urban areas increased, so did sugar intake. Changes in the population composition (the percent urban and the income per capita levels) of the countries sampled explain over 80% of the change in caloric sweetener intake. Urbanization has correlated highly in the developing world with access to processed foods higher in sugar. Urbanization is also linked with greater access to modern mass media, to

Table 2. Trends in availability of caloric sweetener and sweeteners by food location for Americans 2 years of age and older

	Vending	Home	Store/out	Restaurant/ fast food	School	Other	Total
Calories from added sugar							
1977 to 1978	5†	171†	18*†	24*†	8*†	8†	235†
1989 to 1991	4‡	170‡	10*‡	43*‡	6*	9‡	242‡
1994 to 1996	8†‡	198†‡	27†‡	58†‡	7†	21†‡	318†‡
Caloric sweetener as a percent of total energy							
1977 to 1978	0.3†	9.6†	1.0*†	1.3*†	0.4*†	0.4†	13.1†
1989 to 1991	0.2‡	9.5‡	0.6*‡	2.4*‡	0.3*	0.5‡	13.5‡
1994 to 1996	0.4†‡	10.0†‡	1.4†‡	2.9†‡	0.4†	1.1†‡	16.0†‡
Caloric sweetener as a percent of carbohydrate							
1977 to 1978	0.6†	21.5†	2.3*†	3.0*†	1.0*†	1.0†	29.5†
1989 to 1991	0.5‡	19.5‡	1.1*‡	4.9*‡	0.7*	1.0‡	27.8‡
1994 to 1996	0.8†‡	19.6†‡	2.7†‡	5.7†‡	0.7†	2.1†‡	31.5†‡

Sources: USDA Nationwide Food Consumption Survey, 1977 to 1978. Continuing Survey of Food Intake by Individuals 1989 to 1991, and 1994 to 1996.

Statistical significance: $p \leq 0.01$. * a significant difference between 1977 to 1978 and 1989 to 1991; † a significant difference between 1977 to 1978 and 1994 to 1996; ‡ a significant difference between 1989 to 1991 and 1994 to 1996.

Table 3. Trends in the amount of caloric sweetener intake by specific food groups for Americans 2 years of age and older

	Calories from caloric sweetener			Caloric sweetener as a percent of total energy			Caloric sweetener as a percent of carbohydrate		
	1977 to 1978	1989 to 1991	1994 to 1996	1977 to 1978	1989 to 1991	1994 to 1996	1977 to 1978	1989 to 1991	1994 to 1996
Soft drinks	52*†	74*‡	105†‡	2.9*†	4.1*‡	5.3†‡	6.5*†	8.5*‡	10.4†‡
Fruit drinks	18†	19‡	31†‡	1.0†	1.1‡	1.6†‡	2.3†	2.2‡	3.1†‡
Desserts	54*†	47*‡	60†‡	3.0*†	2.6*‡	3.0†‡	6.8*†	5.4*‡	5.9†‡
Sugars and jellies	43*†	31*	31†	2.4*†	1.7*	1.6†	5.4*†	3.6*	3.1†
Candy	7*†	9*‡	16†‡	0.4*†	0.5*‡	0.8†‡	0.9*†	1.0*‡	1.6†‡
RTE cereals	7*†	11*‡	14†‡	0.4*†	0.6*‡	0.7†‡	0.9*†	1.3*‡	1.4†‡
Breads	15*†	13*‡	14†‡	0.8*†	0.7*‡	0.7†‡	1.9*†	1.5*‡	1.4†‡
Coffee/tea	7	5‡	10‡	0.4	0.3‡	0.5‡	0.9	0.6‡	1.0‡
All milk and cream products	9†	10‡	12†‡	0.5†	0.6‡	0.6†‡	1.1†	1.1‡	1.2†‡
Low-fiber fruit/noncitrus fruit Juice	8*†	6*‡	4†‡	0.4*†	0.3*‡	0.2†‡	1.0*†	0.7*‡	0.4†‡
Other	15*†	18*‡	21†‡	0.8*†	1.0*‡	1.1†‡	1.9*†	2.1*‡	2.1†‡
Total	235†	242‡	318†‡	13.1†	13.5‡	16.0†‡	29.5†	27.8‡	31.5†‡

Sources: USDA Nationwide Food Consumption Survey 1977 to 1978, Continuing Survey of Food Intake by Individuals 1989 to 1991 and 1994 to 1996.
Statistical significance: $p \leq 0.01$.
* Significant difference between 1977 to 1978 and 1989 to 1991.
† Significant difference between 1977 to 1978 and 1994 to 1996.
‡ Significant difference between 1989 to 1991 and 1994 to 1996.

better transportation systems, and to larger modern supermarkets (25). Whereas increases in income per capita have occurred hand-in-hand with urbanization, increases in income also play a powerful separate role in food-consumption decisions, in particular, decisions related to the consumption of more processed foods.

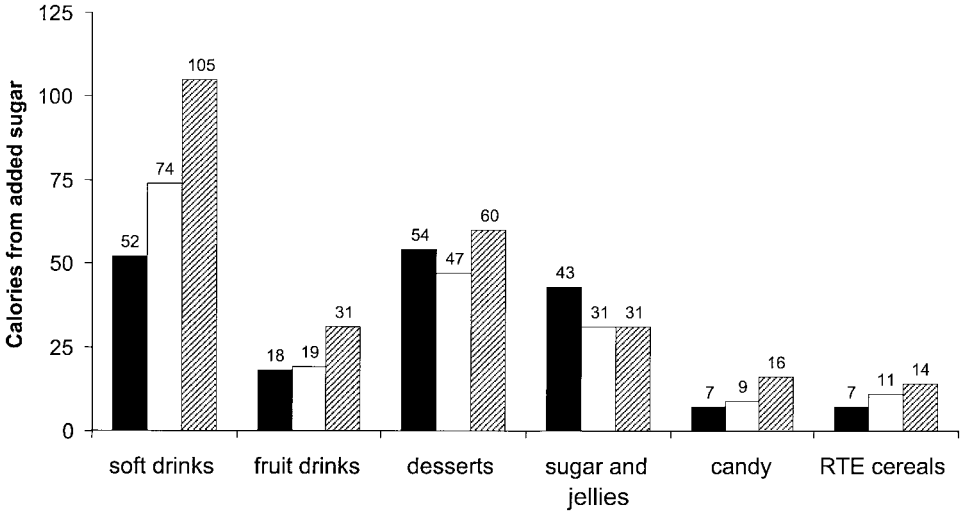

Figure 2: Shifts in food sources of caloric sweetener in the United States. Solid bars, 1977 to 1978; open bars 1989 to 1991; and hatched bars, 1994 to 1996.

Individual intake dietary data, taken from three sets of nationally representative USDA surveys in the United States, highlight the dramatic shifts in caloric sweetener intake between 1977 and 1998 in restaurants and fast food establishments. Moreover, the U.S. data show that soft drinks and sugared fruit drinks represent ~80% of the caloric sweetener increase. These two food groups, along with desserts and sugar/jellies, represent the four major sources of caloric sweetener in the U.S. diet. There are no data available to enable comparison of these U.S. patterns and trends with those of other countries, because most countries with repeated dietary intake surveys do not have a food composition table that includes caloric sweetener as a separate category.

When the results of this study are coupled with earlier studies, we can clearly see the pronounced shift in the world's diet toward increased consumption of caloric sweetener and away from higher-fiber foods. Thus, we are increasingly consuming foods that provide energy but few other nutrients (1,26). Many scholars assert that the reduction in milk consumption in the United States is linked with the increase in intake of these calorically sweetened beverages (4,9,15).

Because of limited research, the implications of these dietary shifts on human health are unclear, and there is still little understanding of replacement issues. It is clear, however, that consuming excessive soft drinks or other high-sugar, low-nutrient foods will either add calories or reduce nutrient intakes. The issue of caloric sweetener and its potential effects on obesity and other metabolic disorders is not yet fully understood or accepted. A longitudinal study by Ludwig et al. (7) showed the effect of increased consumption of sugar-sweetened beverages on increased energy intake and obesity. Other research by Ludwig and others point out that the effect of refined sugar intake on glycemic response represents a potentially important negative health effect of caloric sweetener (5). Among the conclusions from research are that sugar has a very high glycemic index and that consumption of higher caloric sweetener foods and beverages is related to increased dietary intake and other metabolic complications. Excessive added sugar intake may contribute to obesity.

In contrast, many representatives of the food industry maintain that sugar in food and caloric sweetener may have neutral effects on health (6). This viewpoint is often expressed during forums, most often sponsored by the International Life Sciences Institute.

Regardless of the effects, clearly there is a rapid increase in intake of caloric sweetener. If both urbanization and the processing of the food supply continue unabated, this trend in the worldwide diet will persist. Thus, we will inexorably move away from foods that are potentially important sources of calcium and other key nutrients and toward foods that provide fewer nutrients.

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