Book Section:
Moore, JB orcid.org/0000-0003-4750-1550 and Fielding, BA (2022) Demystifying Dietary Sugar. In: Wilson, T, Temple, NJ and Bray, GA, (eds.) Nutrition Guide for Physicians and Related Healthcare Professionals. Humana , pp. 319-328. ISBN 9783030825140

https://doi.org/10.1007/978-3-030-82515-7_30

Chapter 30
Demystifying Dietary Sugars

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Abstract

A preponderance of evidence now definitively links high consumption of dietary sugars to increased energy intakes, increased body weight, and dental caries. High intakes of sugar-sweetened beverages, in particular, are associated with increased risk of type 2 diabetes. While there is increased awareness of global public health recommendations to reduce sugar consumption, added sugars are often difficult to identify on food labels. There are misunderstandings about the relative risks or healthfulness of different types of sweeteners, and terms such as ‘raw’ and ‘natural’ that are used in their marketing. Sugars naturally present in intact foods are not detrimental to health because they are contained within cell walls and have a reduced glycemic response, as a result of their food matrix, fiber, and slower rate of digestion. Therefore, the primary public health message for obesity prevention is to reduce intake of high-sugar snacks and sugar-sweetened beverages. Fiscal policies may help reduce population sugar intakes through prompting reformulation and the reduction of sugars in high-sugar products. The aim of this chapter is to demystify sugars for the healthcare professional and give a balanced overview of the role of dietary sugar in obesity and metabolic health.

Keywords

Sugar; Sugar-Sweetened Beverages; Sugar Tax; Obesity; Agave; Fructose

Key Points

- High dietary intakes of sugars increase energy intake, body weight, and the risk of tooth decay
- High consumption of sugar-sweetened beverages increases risk for type 2 diabetes
- Sugar naturally present in intact foods produces less of a glycemic response than added or free sugars
- Health effects of specific sugars on metabolism beyond excess energy is not clear
- Fiscal policies may help in reducing intake of sugar-sweetened beverages and high-sugar snacks

1. INTRODUCTION

An extensive body of evidence now links excess consumption of sugar to obesity and dental caries. High intakes of sugar-sweetened beverages specifically are associated with increased risk for type 2 diabetes [1]. This is a particular concern for adolescents and young adults who typically consume the highest percentage of their daily calories from sugar-sweetened beverages (>9% in the United States [2, 3]). The confluence of evidence has led to the updating of dietary recommendations related to the consumption of added/free sugars by many public health advising bodies across the world. Moreover, some countries have implemented fiscal (sugar tax) or other policy measures aimed at reducing sugar consumption and preventing obesity. While there is now increased public awareness of the recommendations to reduce sugars and sugar-sweetened beverages in our diets, there remains confusion over terms such as ‘total sugar’, ‘added sugars’, and ‘free sugars’ found on food labels and used by public health officials. In addition, there are misunderstandings about the relative risks or healthfulness of different types of sugars found in foods, and terms such as ‘raw’ and ‘natural’ that are used in their marketing. One example of this problem is ‘raw’ agave nectar, a syrup derived from the agave plant commonly found in health food stores and widely used in foods and beverages. Sales of this product are increasing as a result of its marketing as a natural and low glycemic alternative sweetener to ‘refined’ sugar and high-fructose corn syrup [4]. However, as detailed below agave is, in reality, a highly-refined syrup with a higher fructose content than high-fructose corn syrup [5]. The aim of this chapter is to demystify these terms for the healthcare professional and give a balanced overview of the role of dietary sugar in obesity and metabolic health.

2. TYPES OF SUGAR

2.1 Chemical Classification

Conventionally, the term ‘sugars’ encompasses chemically the monosaccharides (glucose, fructose, galactose) and disaccharides (sucrose, lactose, maltose). These are the lowest molecular weight carbohydrates. Carbohydrates are biomolecules made up of carbon, hydrogen, and oxygen, and an important source of energy in the diet. Glucose, fructose, and galactose are six-carbon hexoses with the chemical formula $C_6H_{12}O_6$, and are the building blocks of disaccharides as well as longer oligo- and polysaccharides. The word saccharide is derived from the Greek word for sugar.

Disaccharides are the product of a condensation reaction between two monosaccharides. The most common disaccharide is sucrose, often called table sugar, which is produced naturally in plants from glucose and fructose. It is extracted and refined, most commonly from sugar cane and sugar beets, but also corn, agave, palm, and numerous other plants and grains (the latter called malt). Glucose and fructose are also found in their free form in fruits, plant juices, and honey. Starch, the principal storage carbohydrate in plants, is a polysaccharide comprised of many glucose monomers. As fruits ripen, their starch breaks down increasing the free sugar content of the fruit and its sweetness.

Maltose is a disaccharide of two glucose molecules and an intermediate of starch hydrolysis found in germinating grains and seeds. Lactose, or ‘milk sugar’, is a disaccharide of glucose and galactose that is intrinsic to milk and dairy-based products, but also an important part of human breast milk, a topic discussed at greater length in Chapter 3.

2.2 Total versus ‘Added’ or ‘Free’ Sugars

Currently, most countries require the declaration of ‘total sugar’ on the nutrition facts labels of packaged foods. Total sugar on labels includes sugars occurring naturally in foods and beverages, such as lactose, as well as sugars added by the manufacturer during processing and preparation.

However, dietary guidelines recommending limiting sugar intakes refer either to ‘free sugars’ (World Health Organisation, UK) or ‘added sugars’ (US, Australia). In recognition of the role of the food matrix on health effects discussed further below, these terms are similar in excluding the sugars present in intact fruits and vegetables as well as lactose naturally present in milk and milk products. The difference between the terms free and added sugars is that the definition of free sugars includes the sugars in juiced or pureed fruit and vegetables, whereas these are excluded from the definition of added sugars (definitions have been summarized in **Table 30.1**).

Therefore, in the US where the reporting of added sugars (under total sugars) on food labels has now been mandated [6], a 250 ml glass of 100% orange juice that contains 26 grams of total sugar will list 0 grams of added sugars on the label while still containing 26 grams of free sugars. This is problematic because in terms of the health risks of dental caries, weight gain, and type 2 diabetes associated with intake of dietary sugar, there is consensus that public guidance and intake monitoring should focus on free sugars [7]. Moreover, as the US Food and Drug Administration’s definition of added sugars excludes fruit purees, the increased use of these as sweetening ingredients have been touted by some in the food industry as a strategy for circumventing the “added sugar label hurdle” [8]. Fruit (and vegetable) puree is often the reason for high free sugar

Table 30.1 Definitions of relevant sugar-related terms. [1]Adapted with permission from Moore & Fielding [11] [1]

Term	**Definition**
Sugars[2]	Conventionally describes chemically the monosaccharides (glucose, fructose, galactose) and disaccharides (sucrose, lactose, maltose). Sugars include those occurring naturally in foods and drinks or added during processing and preparation.
Total Sugars	Currently required for nutrition facts labels on packaged foods in most countries worldwide. Includes sugars occurring naturally in foods and beverages and those added during processing and preparation.
Added Sugars	A required subline under 'total sugars' for US food labels from 2020 [6]. Defined as 'Syrups and other caloric sweeteners used as a sweetener in other food products. Naturally occurring sugars such as those in fruit or milk are not added sugars' [12]; the term 'added sugars' in the US also excludes sugars in juiced or pureed fruits and vegetables that are included in the WHO definition of free sugars.
Free Sugars	'All monosaccharides and disaccharides added to foods by the manufacturer, cook, or consumer, plus sugars naturally present in honey, fruit juices, and syrups' [13]. Under this definition, sugars present in intact fruits and vegetables and lactose naturally present in milk and milk products are excluded.
Monosaccharides	The simplest form of carbohydrates including the three primary hexoses (six-carbon simple sugars): glucose, fructose, and galactose; these are the monomers that make up naturally occurring di-, oligo-, and poly-saccharides.
Disaccharides	Product of condensation reaction between two monosaccharides; includes sucrose, lactose, maltose
Sucrose	A crystalline disaccharide of fructose and glucose found in many plants, predominantly sugar cane and sugar beets. It is extracted and refined and used widely as table sugar.
Lactose	A disaccharide of glucose and galactose. It is often called 'milk sugar' because 100% of 'total sugars' in milk are lactose.

[1] Examples of sugars commonly found as ingredients: sucrose, fructose, glucose, dextrose, maltose, lactose, trehalose, brown sugar, turbinado sugar, demerara sugar, raw sugar, cane sugar, fruit sugar, invert sugar, corn sweetener, corn syrup, high-fructose corn syrup, malt syrup, glucose syrup, glucose-fructose syrup, honey, molasses, date syrup, agave syrup, rice syrup

content in foods for infants and toddlers [9], and fruit purees are also often found in yogurts that can contain a surprisingly high amount of free sugars [10].

2.3 Sugars versus Complex Carbohydrates in the Context of Real Food

Although the chemical structure and biological handling of sugars are indistinguishable regardless of source, the food matrix greatly impacts the metabolic effects of sugar. For example, intact fruit provides much greater satiety and a lower glycemic effect than its comparable fruit juice [7]. For this reason, sugars contained within the cell walls of fruit are not 'counted' as added sugars. Whereas high fruit and vegetable intakes are associated with beneficial effects on body weight, increased fruit juice consumption contributes to weight gain and the risk of dental caries. Current pediatric recommendations underscore that 100% fruit juice offers no nutritional benefits over whole fruit; indeed, juice is lacking the protein and fiber found in whole fruit and intakes should be limited [14]. While 100% fruit juices may provide some essential nutrients, they can also provide almost as much sugar as carbonated soft/fizzy drinks and frequent consumption of acidic fruit juices have been shown in meta-analysis to contribute to tooth erosion in children [15]. In contrast, higher consumption of milk has been associated with lower risk for tooth erosion [15]. Although some studies have suggested that lactose may be less cariogenic than other sugars, there is also a pH effect with the food matrix components in unsweetened dairy products providing a buffering capacity that is protective to teeth enamel [16].

When glucose is consumed as a sugar-sweetened beverage or as fruit juice, absorption into the blood is rapid, and although plasma concentrations of glucose are partly determined by the balance between the arrival of ingested glucose into the blood and uptake into tissues, a compensatory decrease in endogenous (hepatic) glucose production (EGP) also influences plasma glucose levels. Stable isotope techniques have shown that in people with type 2 diabetes, a reduced suppression of EGP significantly contributes to the higher plasma glucose concentrations compared to healthy controls after an oral glucose tolerance test **(Fig. 30.1)**. Thus, postprandial glycemia is dependent on the degree of hepatic insulin sensitivity.

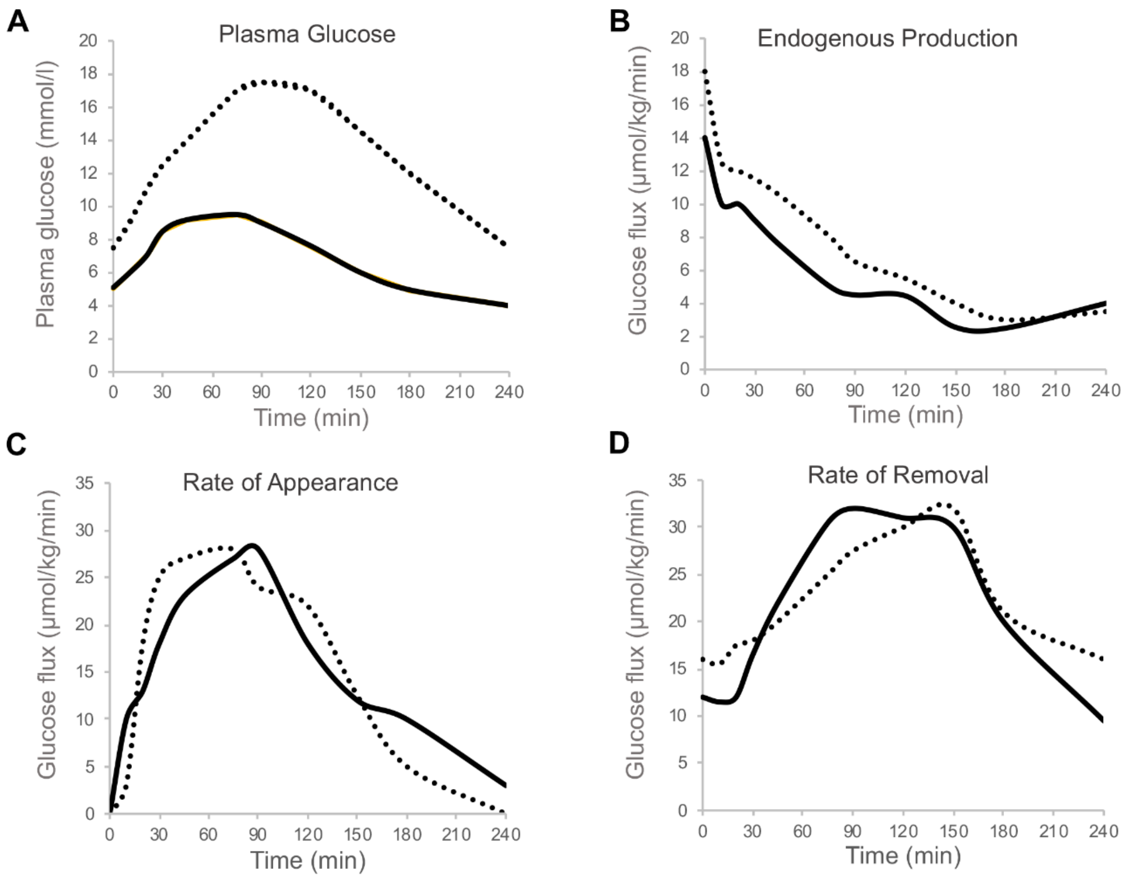

Fig. 30.1 Glucose fluxes contributing to plasma glucose concentrations in healthy people (solid line) and people with type 2 diabetes (dashed line) after an oral glucose tolerance test (OGTT, 75 g glucose). A. plasma glucose concentrations; B. rate of endogenous (hepatic) glucose production; C. rate of glucose appearing in the blood from the drink; D. rate of glucose removal from the blood. Data taken from Lund and colleagues [17].

As noted previously, complex carbohydrates, such as starch, are composed of a series of glucose monomers. However, starch and the equivalent glucose load are not necessarily equal with regards to glucose-raising potential. One of the reasons for this is that in real life, starch is usually eaten as part of a mixed meal, with slower gastric emptying than after a drink. We can take potato mashed with butter as an example. This food produces a much lower glucose spike than does a comparable amount of available carbohydrate in a sugar-sweetened beverage (**Fig. 30.2**).

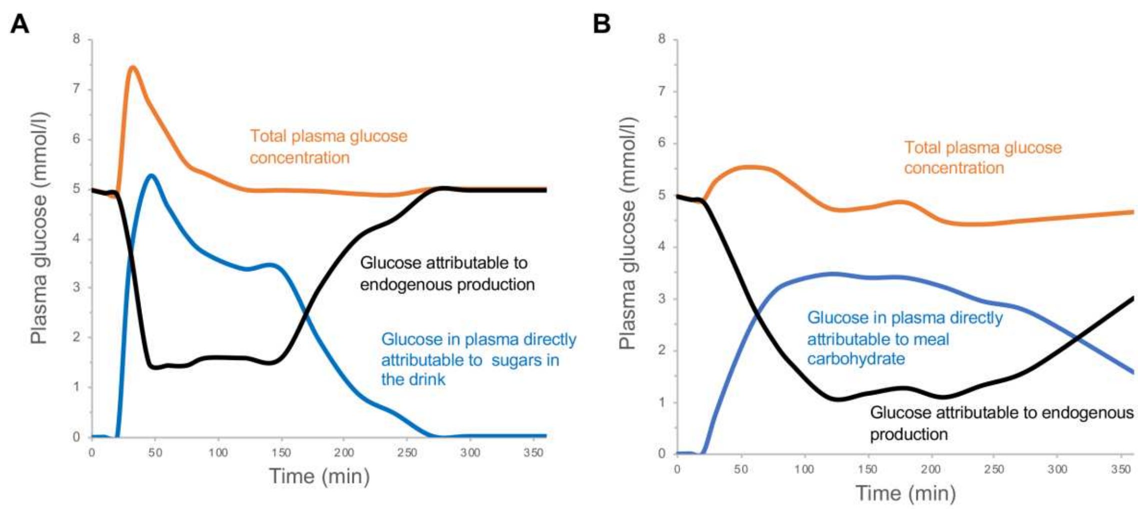

Fig. 30.2 Determinants of plasma glucose concentrations in healthy individuals after either A. a drink containing 35 g glucose, data estimated from [18, 19]; or B. a comparable amount of available carbohydrate in a serving of mashed potato containing 20 g fat from butter, author's (BAF) unpublished data.

We can see that the glucose in plasma directly attributable to glucose from the drink has returned to baseline by 270 min whereas the glucose in plasma directly attributable to glucose from the potato meal is still above baseline by the end of the study at 360 min. If consumed with its skin, some lean protein, and vegetables, the response would be even further blunted. Moreover, while the composition of a meal influences the glycemic response, recent large-scale precision nutrition studies have demonstrated both that numerous factors influence the postprandial response and that there is tremendous inter-individual variability even to the same foods [20, 21]. Therefore, simplistically representing potatoes, rice, bananas, or other whole plant foods in terms of spoonfuls of sugar, as occasionally depicted, is very misleading.

3. SUGAR, OBESITY, AND METABOLIC HEALTH

3.1 Public Health Recommendations

In recent years numerous public health advisory bodies have updated and strengthened their guidelines around dietary sugar intake **(Table 30.2)**. The scientific basis for restricting the consumption of free sugars to a maximum of 10% of total dietary energy came from two independent meta-analyses commissioned by the World Health Organization (WHO) and the UK's Scientific Advisory Committee on Nutrition. These concluded that there is a causal relationship between a high-sugar diet and obesity [22, 23]. However, with respect to type 2 diabetes, the strongest evidence is seen for a relationship with the consumption of sugar-sweetened beverages specifically, rather than for total sugars [23]. Nonetheless, with obesity, a leading risk factor for cardio-metabolic disease, reducing dietary sugar intake is presumed to be beneficial for anyone wishing to mitigate risk of developing cardiovascular disease, type 2 diabetes, and fatty liver.

Table 30.2 Organizational recommendations for the consumption of dietary sugars[1]
[1]Adapted with permission from Moore & Fielding [11]

Organisation (Year)	Recommendations
World Health Organisation (2015)	Intakes of free sugars should be reduced to less than 10% of total energy intake in both adults and children [24].
UK Scientific Advisory Committee on Nutrition (2015)	The average population intake of free sugars should not exceed 5% of total dietary energy for those aged 2 years or over [23].
U.S. Department of Health and Human Services (2015)	Consume less than 10% of calories per day from added sugars [12].
Australian National Health and Medical Research Council (2013)	Limit intake of foods and drinks containing added sugars such as confectionary, sugar-sweetened soft drinks, and cordials, fruit drinks, vitamin waters, energy and sports drinks [25].
European Food Safety Authority (2010)	At the time EFSA concluded the available evidence was insufficient to set an upper limit for intake of sugars. However, this is currently being reviewed with an aim of setting "a tolerable upper intake level for total/added/free sugars if the available data allow it", with publication anticipated in 2021 [26].

There has been a staggering global tripling of the population classified as obese since 1975. In an attempt to reduce this rising tide, the WHO has proposed different economic policies. The most common of these is a tax on sugar-sweetened beverages. Both modelling and studies evaluating the impact of sugar tax have indicated that purchases or sales decrease significantly with taxation amounts of around 8 to 10% [27]. A modelling study based on UK dietary habits concluded that a 20% price increase on 'high sugar snack foods' in the UK would have substantially more impact on the average weight change of adults than would a similar price increase on SSBs [28]. We have previously cautioned that fiscal policies aimed at reducing consumption of sugar might be useful but they fail to incentivize the consumption of healthy foods. Ultimately, tackling obesity and diet-related disease requires a sustained group of initiatives aimed at reducing health inequalities [29]. More recently, evidence is accruing of 'a perfect storm' with a higher mortality rate when the coronavirus disease COVID-19 infects people with obesity [30].

3.2 Common Sources of Sugar and Marketing

Major challenges for consumers who wish to cut down their intake of sugars include both the ubiquity of sugars in foods and the myriad ways that sugars are either disguised or marketed. While the majority of the public anticipate that sugar will be in cakes and confectionary, they underestimate the sugar content of perceived healthy foods such as yogurts, under the so-called 'health halo effect' [31]. Added sweeteners are found in numerous foods consumers might not expect such as peanut butter, baked beans, and many sauces and condiments. Moreover, added sugars are often missed by consumers on ingredient lists because of the variety of names that mono- and di-saccharides may be disguised under. Although we list 25 names in the footnote of **Table 30.1**, we caveat this is not a comprehensive list. In more recent years the marketing of 'natural sugars' has become problematic. When surveyed, consumers stated preferences are for honey, agave, and date syrups and 'raw cane sugar', with table sugar the least popular. Their preferred sweetening ingredients were based on the 'natural' sugars being perceived as 'healthier' and/or less processed [32].

For example, agave nectar or syrup is marketed as a natural sweetener but is processed almost identically to high-fructose corn syrup (HFCS); and it contains approximately 84% fructose whereas HFCS generally contains either 42 or 55% fructose [11]. It is noteworthy that whether sourced from sugar cane, sugar beets (common in the European

Union), agave, or corn, extracting sugars from these fibrous plants requires a similar amount of (extensive) processing to produce even raw sugar. Regardless of source or name, the dominant compounds in all sweeteners are monosaccharides and disaccharides; it is these substances that lead to a significant increase in the energy density of foods that contain added sugar **(Table 30.3)**. However, the unwitting consumer just sees "agave" on the ingredients list and may assume the product is healthier than a product listing sugar as an ingredient. Recent research has underscored that chemical or alternative names for sugars found on ingredient labels is not always helpful for consumers; 30-50% of them, when surveyed, incorrectly identified sucrose, fructose, and dextrose as being non-caloric sweeteners [33].

Table 30.3 Energy and sugars found per 100 grams in common dietary sweeteners[1] Adapted with permission from Moore & Fielding [11]

Sweetener	Energy (kcal)	Water (g)	Total Sugars (g)	Sucrose (g)	Glucose (g)	Fructose (g)
White sugar	385	0.02	99.8	99.8	0.0	0.0
Brown sugar	380	1.34	97.0	94.6	1.4	1.1
Honey	304	17.1	82.1	0.9	35.8	40.9
Molasses	290	21.9	74.7	29.4	11.9	12.8
Maple syrup	260	32.4	60.5	58.3	1.6	0.5
Agave syrup	310	22.9	68.0	0.0	12.4	55.6
Golden syrup	298	20.0	79.0	32.8	23.1	23.0
HFCS[2]	281	24.0	75.7	nr	nr	nr

[1]Data taken from the U.S. Department of Agriculture Food Data Central database [34] and the Public Health England Composition of Foods Integrated Dataset [35].
[2]HFCS, high-fructose corn syrup; nr, not reported

3.3 Sugar-Sweetened Beverages

Sugar-sweetened beverages are hot or cold drinks sweetened with any kind of added sugar. In many cases they have no other nutritive value. They include carbonated sweet drinks (often called soda), fruit drinks, sports drinks, energy drinks, sweetened waters, and coffee and tea beverages with added sugar, and are a leading source of dietary sugar in many countries. The evidence for a causal relationship between consumption of sugar-sweetened beverages, obesity, and consequent metabolic dysfunction has been well summarized [23] but an independent effect on the risk of type 2 diabetes has been surprisingly difficult to prove [36]. Despite public health messages and guidelines to reduce intake, worldwide longitudinal studies have not shown significant decreases in recent years although some trends in the right direction have been observed [37]. Underlying reasons for high consumption of sugar-sweetened beverages are complex; varying by age, sex, race/ethnicity, geography, socioeconomic status, and associated with less healthy behaviors [38]. Moreover, replacement of sugar-sweetened beverages with sugar-free (diet) alternatives has not led to a reduction of energy intake.

3.4 Is Fructose Worse for Health?

There are two sides to fructose; on the one hand, refined fructose is marketed as a naturally occurring fruit sugar that can be consumed in smaller quantities than other sugars to achieve the same sweet taste. It is also metabolized differently than glucose, and is not recognized by the beta-cell. But on the other hand, although fructose does not directly elicit an insulin response, it can do so indirectly by conversion to glucose. Using stable isotope tracers, it has been calculated that 26% of fructose carbons are converted to glucose when 0.5 g/kg was consumed with a mixed meal, and 19% are converted in the presence of a mixed meal that also contains glucose [39]. However, fructose is predominantly metabolized by the liver to products such as glycerol and fatty acids, leading to significantly greater postprandial hypertriglyceridemia than glucose when consumed in supra-physiological amounts in acute studies [40]. The use of hypercaloric, supra-physiological doses in intervention trials has been a major confounding factor and the matter of whether or not hepatic lipogenesis and non-alcoholic fatty liver disease pathogenesis in humans occur independently of excess energy remains unresolved [41]. There is only a limited amount of evidence that hypercaloric fructose and glucose diets have similar effects on liver fat and liver enzymes in healthy adults [42].

Fructose has been scrutinized in part because intakes of HFCS have increased dramatically in parallel with the increase in obesity and metabolic disease in the United States since its introduction in 1967 [40]. As alluded to previously, its name is in fact a misnomer as HFCS generally contains either 42 or 55% fructose—much less than agave nectar at 84%. Metabolically, the fate of the glucose and fructose monomers in HFCS is no different from the monomers of glucose and fructose derived from sucrose (after cleavage by the enzyme sucrase in the intestine), or the syrups produced from sugar cane or sugar beet. In the European Union, where syrups are typically derived from sugar beet, these sugars are found on food labels as glucose-fructose syrup, fructose-glucose syrup, or isoglucose, depending on the ratio of monomers [40]. Interestingly, these ingredients and the very popular baking ingredient 'golden syrup' **(Table 30.3)** have yet to be as demonized by consumers as HFCS, despite the fact that they all contribute equally to excess energy intake. The point remains, nonetheless, that fructose is almost never consumed in isolation and to date proving an adverse metabolic effect of specific sugars at typically consumed levels that is independent of their contribution to excess energy has been difficult.

4. CONCLUSIONS

High intakes of dietary sugars have fueled the obesity pandemic. The over-consumption of sugar-sweetened beverages has an associated higher risk for developing type 2 diabetes. Worldwide differences in the terminology of added, free, and total sugars, and the guidelines relating to dietary sugar have likely hindered progress in understanding how to reduce the high global consumption. Significant misunderstandings exist, among consumers and health professionals alike, about the relative healthfulness of different sugars and sweeteners. While the free sugars in fruit juice and fruit purees produce sharp spikes in blood glucose levels, intact fruit has a reduced glycemic response because the sugars are contained within cell walls and the accompanying fiber slows the rate of digestion. Fruit also contains micronutrients and phytochemicals that are more beneficial to health. Although fiscal policies may help in reducing intake of sugar-sweetened beverages and high-sugar snacks, it is imperative that important confounding factors, such as social inequalities, must be taken into consideration.

SUGGESTED FURTHER READING

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