Trends in Food Science & Technology 56 (2016) 158–166

Contents lists available at ScienceDirect

Trends in Food Science & Technology

journal homepage: http://www.journals.elsevier.com/trends-in-food-science-and-technology

Commentary

The role of sugars and sweeteners in food, diet and health: Alternatives for the future

Cathrina H. Edwards [a, 1], Megan Rossi [b], Christopher P. Corpe [c], Peter J. Butterworth [a], Peter R. Ellis [a, *]

[a] *Biopolymers Group, Diabetes and Nutritional Sciences Division, King's College London, Franklin-Wilkins Building, 150 Stamford Street, London, SE1 9NH, UK*

[b] *Diet and Gastrointestinal Health Group, Diabetes and Nutritional Sciences Division, King's College London, Franklin-Wilkins Building, 150 Stamford Street, London, SE1 9NH, UK*

[c] *Diet and Cardiovascular Health Group, Diabetes and Nutritional Sciences Division, King's College London, Franklin-Wilkins Building, 150 Stamford Street, London, SE1 9NH, UK*

A R T I C L E I N F O

Article history:
Received 30 October 2015
Received in revised form
3 June 2016
Accepted 12 July 2016
Available online 15 July 2016

Keywords:
Sugar
Sweetener
Health
Phytochemicals
Obesity

A B S T R A C T

Background: There is currently great interest in reducing the sugar content of foods to control dietary intake and curb obesity rates. Despite a lack of consensus from the scientific literature about the adverse effects of sugars on health, many health professionals and new dietary guidelines place pressure on industry to seek alternative sweetening solutions.

Scope and approach: We discuss the nutritional characteristics and health implications of nutritive and non-nutritive sweeteners. The role of traditional sweeteners, which are often overlooked in the debate about sugars and health, is emphasised.

Key findings and conclusions: Trends in future sweetener use will likely be influenced by increasing obesity prevalence and consumer demand; however, it is not yet clear which sweetener provides the best solution for this purpose. Given the main concern about sugars is their disproportionate contribution to dietary energy intake, non-nutritive sweeteners (e.g., aspartame, stevia), which provide intense sweetness but minimal caloric value, are increasing in popularity. However, their assumed role in facilitating body weight management is far from established, and many questions remain about their long term effects on energy metabolism and safety. Traditional sweeteners (e.g., maple syrup, honey, carob, and agave) have been safely consumed for generations, and although they contribute to energy intake, these sweeteners tend to have lower glycaemic potency than refined sugars. Moreover, traditional sweeteners contain a plethora of nutrients and bioactive compounds (e.g., polyphenolics) that may be of potential benefit to health.

The sweet-tasting mono- and di-saccharides, including glucose, fructose and sucrose, are ubiquitous and naturally present in fruit and vegetables. These sugars have long been part of the human diet, although the amount and source of sugars that are consumed has changed, reflecting sweetener availability and affordability. In precolonial times, sweet flavourings were obtained from natural, less-refined and often local sources. Honey is probably the world's oldest sweetener, and was used by the Ancient Egyptians around 2100 BCE (Erejuwa, Sulaiman, & Ab Wahab, 2012a). In the 17th century, maple syrup, obtained by boiling the sap of maple trees (*Acer saccharum* Marsh.), was the predominant sweetener used in the Americas, whereas in the Mediterranean area, carob (*Ceratonia siliqua* L.) was used for this purpose. In the 18th century, technological advances meant that sucrose extracted from cane (*Saccharum officinarum* L.) and beets (*Beta vulgaris* L.) became more available and affordable, and soon sucrose or 'table sugar' became the primary sweetener. Since the 19th century, global sugar production has increased enormously (Fig. 1), and by the 1950s, refined sugars were used in a wide range of foods worldwide. During this

* Corresponding author.
E-mail addresses: cathrina.edwards@kcl.ac.uk (C.H. Edwards), megan.rossi@kcl.ac.uk (M. Rossi), christopher.corpe@kcl.ac.uk (C.P. Corpe), peter.butterworth@kcl.ac.uk (P.J. Butterworth), peter.r.ellis@kcl.ac.uk (P.R. Ellis).
[1] Present address: Institute of Food Research, Norwich Research Park, Norwich, NR4 7UA, UK.

http://dx.doi.org/10.1016/j.tifs.2016.07.008
0924-2244/

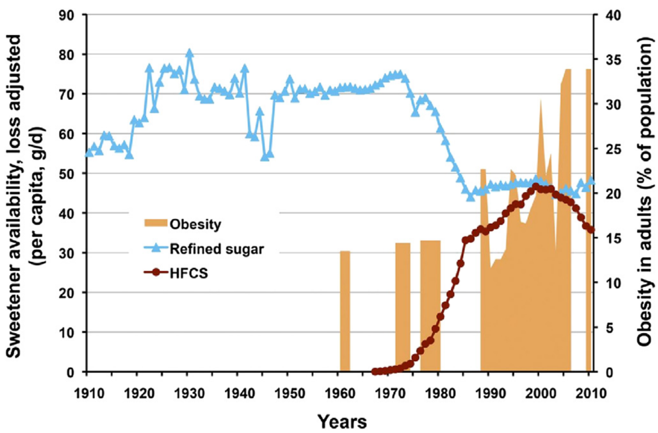

Fig. 1. Trends in sweetener availability and obesity over time. This represents trends in the US. For UK data, refer to (Johnson et al., 2007). HFCS; High-fructose corn syrup. Reproduced with permission from (White, 2013).

time, the availability of processed foods (e.g., pre-prepared products, typically made from substances that have been extracted or refined from whole/raw materials) increased, lifestyles became more sedentary, and the prevalence of obesity began to rise, particularly in more economically developed countries.

Today it is estimated that over 39% and 13% of the global adult population is overweight and obese, respectively, and most people live in countries where being obese and overweight is a greater cause of death than being underweight (WHO Media Centre., 2015). Fundamentally, obesity develops when the energy intake of an individual exceeds their energy output or expenditure; i.e., the subject is in a state of positive energy balance. All energy-yielding food components can potentially contribute to a positive energy balance, but many believe sugars are the major culprit (Bray, 2010; MacGregor & Hashem, 2014).

Glucose is required by the body as one of the primary sources of fuel for cellular metabolism. However, recent data has shown that sugar intakes are in excess of recommendations (NDNS., 2014). On average, across the entire UK population, **free sugars**[2] in foods and drinks, which according to the World Health Organisation (WHO) should account for less than 10% of total food energy intake, are contributing 13% (NDNS., 2014). Children and young people (aged 4–18) in particular have an especially high intake of sugars, and on average, **added sugars**[3] in foods and drinks account for ~15% of food energy intakes in this age group. Furthermore, there are some young people, particularly males, who consume as much as 189 g free sugars/day, accounting for ~32% of their energy intake (NDNS., 2014). This is over three times as much as the recommended intake, and potentially puts this group at an increased risk of developing obesity and the associated metabolic diseases, especially if a higher energy intake is combined with a sedentary life style. Frequent intake of sugars can also be detrimental to dental health, because bacteria in the mouth ferment sugars and produce acid, which is damaging to the tooth enamel. These data have led to heightened concerns about the potential negative impact of the consumption of added sugars on public health and, as a result, government and health agencies across the world have called for further research on the link between sugars and health.

1. New dietary guidelines & implications for the food industry

Recent evaluations commissioned by the WHO have concluded that limiting the amount of sugar added to foods and decreasing the intake of sugar sweetened beverages (which are a major source of added sugars) would be beneficial in promoting public health, particularly with regard to reducing the risk of dental caries, type 2 diabetes and cardiovascular disease (WHO., 2015). Consequently, the WHO released a new guideline in March 2015 which recommends that "*adults and children reduce their daily intake of free sugars to less than 10% of their total energy intake. A further reduction to below 5% or roughly 25 g (6 teaspoons) per day would provide additional health benefits*" (WHO., 2015). Overall, there seems to be a consensus among government agencies and regulatory bodies that sugars should be targeted as a potential means of reducing energy intakes and thereby curbing obesity rates. It is noteworthy, however, that no such consensus has been reached across the scientific literature, and the extent to which sugars as an isolated nutrient group are responsible for the increased prevalence of obesity continues to be disputed (Kahn & Sievenpiper, 2014).

Whether one agrees with the new guidelines or not, the recent publicity surrounding the sugar and health controversy draws attention to the use of sugars and other sweeteners in food products. Sugars are of course naturally present within many food products (e.g., fruits, vegetables, dairy products) and can be derived from the hydrolysis of the starch present in cereals, pulses and potatoes. However, sugars and other sweeteners are also added to food and beverages during processing and preparation. Although there is no chemical difference between the sugars that are naturally present within the food and the added sugars, there are concerns that products containing added sugars provide minimal nutritional value and are therefore making a disproportionate contribution to total energy intake (MacGregor & Hashem, 2014). Indeed, the main sources of sugars consumed in the UK population are soft drinks and fruit juices, which together contribute on average ~30% of sugars intake for those aged 4–64 years (NDNS., 2014). The amount of sugars that is added to products during food processing has therefore come under particular scrutiny (MacGregor & Hashem, 2014); hence, the food industry is now under pressure to reduce the sugar content of their processed products.

In this viewpoint article, we will consider nutritionally-relevant properties of various sweeteners, ranging from the latest low calorie sweeteners to the more traditional sweet-tasting products.

2. Terminology

An overview of some common sweet-tasting compounds and their properties is provided in Table 1. For the purpose of this article, sweeteners providing energy will be described as 'nutritive sweeteners' (NS), whereas those that provide no/negligible amounts of energy will be described as 'non-nutritive sweeteners' (NNS). Nutritive sweeteners are further sub-categorised into sugars (i.e., sweet-tasting mono- and di-saccharides) and bulk sweeteners (e.g., polyols). The term 'traditional sweeteners' will be used to describe naturally sweet products derived from plant and animal-sources (e.g., maple syrup and honey).

Most of the NNS are produced by chemical synthesis, and are therefore described as 'artificial', although some NNS (e.g., stevia) are extracted from natural sources. New and emerging sweeteners

[2] Free sugars are defined as all monosaccharides (e.g., glucose and fructose), and disaccharides (e.g., sucrose, maltose) that are added to foods and beverages by the manufacturer, cook or consumer, and sugars that are naturally present in honey, syrups, fruit juices and fruit juice concentrates, but not those present in dairy products (e.g., lactose).

[3] Added sugars are defined as sucrose, fructose, glucose, starch hydrolysates and other isolated sugar preparations used as such or added during food preparation and manufacturing.

Table 1
Overview of common nutritive and non-nutritive sweet-tasting compounds and their relative sweetness, glycaemic index and caloric value.[1]

Sweetener	Relative sweetness	Glycaemic index	Energy (kcal/g)
Nutritive sweeteners			
Sugars (NS)			
Monosaccharides			
Glucose	50[b]	100[b]	4[b]
Fructose	150–180[b]	19–23[b]	4[b]
Galactose	26[c]	23[c]	4[b]
Disaccharides			
Maltose	40[b]	105[b]	4[b]
Sucrose	100[b]	61–65[b]	4[b]
Lactose	20–40[b]	46[b]	4[b]
Bulk sweeteners (NS)			
Erythritol	60–80[a]	0[b]	0.2[b]
Isomalt	45–65[b]	2[b]	2.0[b]
Lactitol	35–40[b]	6[b]	2.4[b]
Maltitol	50–90[b]	35–52[b]	3.0[b]
Mannitol	50–72[b]	0[b]	1.6[b]
Sorbitol	50–100[a]	9[b]	2.6[b]
Xylitol	100[b]	7–13[b]	3.0[b]
Tagatose	92[b]	0[b]	1.5[b]
Non-nutritive sweeteners			
Acesulfame-K	20,000[a]	0	0
Aspartame	18,000–20,000[a]	0	4
Cyclamate	3000[a]	0	0
Neohesperidin DC	190,000[a]	0	0
Saccharin	30,000–50,000[a]	0	0
Sucralose	60,000[a]	0	0
Thaumatin	200,000–300,000[a]	0	0
Steviol glycosides	1000–1500[b]	0	0

[1]Sweetness is expressed relative to sucrose, which has a relative sweetness index of 100.
Data from [a] Mortensen, 2006, [b] Chattopadhyay, Raychaudhuri, & Chakraborty, 2014, [c] Coultate, 2016.

that have chemical structures (e.g., proteins or modified sugars) that differ from the compounds that are typically used within these sweetener categories have been described elsewhere (O'Brien-Nabors, 2011) and will not be covered in this review.

3. Non-nutritive sweeteners

Over the past century, scientists have worked on the development of NNS, and in the past two decades, growing concerns about increased incidence of type 2 diabetes and obesity have led to an increase in their availability and use (Ng, Slining, & Popkin, 2012). Most NNS are chemically synthesised ('artificial') and are potent sweeteners, which makes them a cost-effective option because only small quantities are required to satisfy the demand for a sweet taste (Gwak, Chung, Kim, & Lim, 2012; Levin, Zehner, Saunders, & Beadle, 1995). Unlike NS, which provide energy from the metabolism of carbohydrate, NNS provide virtually no metabolisable energy when used as a sugar substitute (Table 1). The high-intensity sweeteners that are currently approved for use in the EU are aspartame (E951), saccharin (E954) acesulfame-K (E950), cyclamate (E952), neohesperidin DC (E959), sucralose (E955), thaumatin (E957) and also the recently approved steviol glycosides (E960) a natural extract from *Stevia rebaudiana* Bertoni (Yang, 2010).

In view of the major public health challenges of today, it is understandable that NNS, which provide an intensely sweet flavour, but with fewer calories, have a certain appeal. There is limited data available on the use of these NNS on a population level, but one study estimated that in 2003–2004, 15% of the US population consumed food or beverages containing NNS, compared with only 3% in 1965 (Mattes & Popkin, 2009). The increase in NNS intake over this time reflects the increased availability of 'diet' products, which is, in turn, fuelled by the growing prevalence of obesity and diabetes (Gardner et al., 2012). Paradoxically, there is very little evidence to show that NNS use has either beneficial or negative effects on obesity, despite both forward and reverse causalities being proposed (Mattes & Popkin, 2009). Furthermore, although consumers report choosing NNS as a means of reducing total calorie intake, sugar consumption data suggests that NNS are not being used to replace added sugars, but rather they supplement them (Gardner et al., 2012). These are important considerations which may hinder the expected role of NNS in supporting weight loss.

One limitation of NNS is that they do not activate the same physiological responses that NS would normally achieve. It has been suggested that NNS trigger an ambiguous psychobiological signal that leads to increased appetite and therefore energy intake (Ferreira, Generoso, & Teixeira, 2014; Gardner et al., 2012; Mattes & Popkin, 2009). This effect is less problematic when NNS are consumed as part of an energy-yielding food, because the other food components provide sensory stimuli that signal appropriate metabolic and satiety responses (Mattes & Popkin, 2009). Considering, however, that NNS are widely used to improve the palatability of non-energy yielding diet-products, the lack of satiation from these products may be counter-productive in supporting weight loss (Mattes & Popkin, 2009; Mortensen, 2006). There is also some concern that habituation to the high sweetness of NNS may perpetuate a preference for sweet food and drink, and may therefore encourage sugar dependency (Mattes & Popkin, 2009; Yang, 2010). There is insufficient evidence, however, to determine whether or not the use of NNS and diet products translate into increased total energy intake, and the effect (if any) on body mass index has yet to be determined.

Aside from the questionable efficacy of NNS in aiding weight loss and preventing diabetes, the extent to which NNS can be successfully used as a sugar substitute is finite. There are limitations on the amount of NNS that can be used in food without negatively impacting on product quality. For instance, NNS can be unstable under certain processing conditions and have undesirable sensory properties, which make them unsuitable for various product applications. There are also restrictions on the amount of NNS that can be safely consumed (i.e., acceptable daily intake limits are typically no more than 0.3–3 g NNS/d for a 75 kg adult, depending on the NNS). Although the approved sweeteners have been subjected to stringent assessments by regulatory panels, there are still concerns among consumers with regard to the safety and long-term effects of these sweeteners (Gardner et al., 2012). Most of the NNS are artificial (i.e., chemically synthesised) compounds and therefore unnatural introductions (i.e., termed 'xenobiotics') to the human diet. Because NNS are not digested in the small intestine and enter the large intestine, concerns have been raised about their impact on the human gut microbiota. A recent study reported that NNS consumption in mice and humans increased the risk of glucose intolerance through modulation of both the functionality and composition of the gut microbiota (Suez et al., 2014). It has been proposed that such effects may underpin suggested links between sweeteners and increased diabetes risk; however, this is a new emerging concern and further research is required. NNS can also be unacceptable to certain consumer groups; for example, those suffering from phenylketonuria (a rare metabolic disorder) must avoid aspartame.

Overall, despite the initial appeal of low-calorie sweeteners, the vast majority of consumers do not use NNS, and NS are still by far the main source of sweet flavour in the diet. Although increasing the availability of manufactured products containing NNS may lead to an increase in their use, it seems likely that NS will continue to be the main source of sweetness for years to come.

4. Nutritive sweeteners

Glucose, fructose, and galactose are the main sweet tasting monosaccharides that occur in food and beverages. These sugars can be chemically combined to form naturally occurring disaccharides, e.g., sucrose (fructose + glucose), lactose (glucose + galactose) and maltose (glucose + glucose), and are also the building blocks of a wide range of oligo- and poly-saccharides (e.g., starch, maltodextrins and fructans). Glucose and fructose are also the main components of high fructose corn syrup (HFCS, made up of fructose and glucose) and table sugar (sucrose), which are the most common sweeteners used today. NS are typically hydrolysed into individual monosaccharides in the small intestine, and subsequently absorbed and metabolised to yield dietary energy (Table 1). For labelling purposes, most sugars are considered to provide 4 kcal/g. However, subtle variations in chemical structure between different sugar compounds influence the way in which they are digested, absorbed and metabolised. These variations are evident in the glycaemic index (GI) of individual sweet-tasting mono- and di-saccharides (Table 1) (Foster-Powell, Holt, & Brand-Miller, 2002). The main health concerns surrounding sugars and sugar-rich products are their cariogenic properties, and that their excessive intake, from sources that provide little other nutritional value, may be contributing to a positive energy balance. It is important to note that for individuals affected by hereditary fructose intolerance (i.e., a rare metabolic disorder resulting from deficiency of hepatic fructose-1-phosphate aldolase activity), the consumption of fructose and sucrose has severe detrimental effects on health and must be completely avoided (Oppelt, Sennott, & Tolan, 2015).

Polyols (i.e., sugar alcohols) are saccharide derivatives which occur naturally in fruit, vegetables and some fermented foods, and can be chemically manufactured by hydrogenation of mono- or disaccharides. Compared with sugars, polyols (e.g., xylitol, maltitol, sorbitol) are poorly absorbed and therefore provide fewer calories and lower glycaemic responses (Table 1) (Gwak et al., 2012). These characteristics make them popular for use as sweeteners in diabetic and low-calorie food and drink products. Furthermore, most polyols are not readily fermented by oral bacteria and are therefore non-cariogenic, which make them particularly well-suited for use in chewing gum (i.e., xylitol and sorbitol are commonly used). Polyols are often used in combination with NNS, but in contrast to NNS, polyols have a relatively lower sweetness index, which enables them to be used in larger quantities (i.e., as a bulk sweetener). The amount of polyols that should be consumed is limited, however, because their poor gastrointestinal tolerance causes laxation when consumed at higher doses (i.e., doses >20–60 g/meal, although tolerance varies) (Mortensen, 2006). Moreover, for those with hereditary fructose intolerance, food products containing sorbitol (which is metabolised to fructose in the body) are not tolerated.

5. Traditional sweeteners

Traditional sweeteners are obtained from bees (e.g., honey), plant and tree sap (e.g., maple syrup, agave nectar), fruits (e.g., carob syrup), seeds, roots (e.g. Yakón syrup) and leaves (e.g., stevia). These products have traditionally been used as primary sweeteners in many countries, and offer consumers familiar and natural sources of sweetness. In contrast to refined sweeteners, which are typically extracted from plant sources, most traditional sweeteners are consumed within their natural matrix with minimal pre-processing. The exact composition and sensory properties of natural products will depend on botanical origin, environmental growth conditions and processing factors. For example, there are many different types of honey products with distinct flavours reflecting the flowering plants in the vicinity of the bee hives (Bogdanov, Jurendic, Sieber, & Gallmann, 2008). These sensory properties originate from aromatic compounds that are naturally present within the product (e.g., vanillin and furfural), and/or compounds that develop during processing (e.g., Maillard products generated during heat treatment) (Li & Seeram, 2010). For some applications, inconsistent product characteristics present a challenge, but for some other purposes, these natural variations may provide appealing culinary opportunities and a welcome versatility.

Traditional sweeteners are classed as NS, as they contain a high proportion of sugars. Sucrose, fructose and glucose together constitute at least 50% of plant-derived syrups and honey (Fig. 2), although small amounts of polyols may also be present and contribute to sweetness overall. One difference between refined sugars (i.e., table sugar) and traditional sweeteners is that the latter are often supplied in a liquid form. The relatively high moisture content of liquid sweeteners (~17–35%) means that their energy

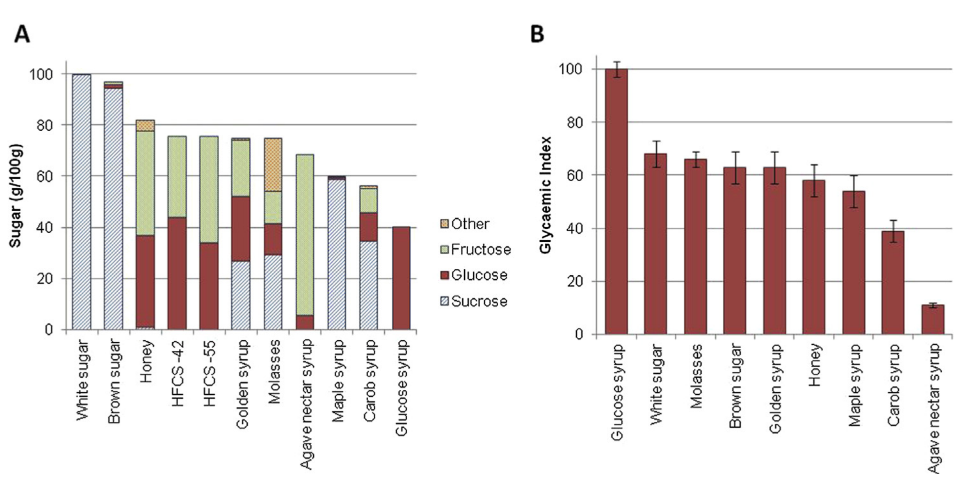

Fig. 2. Sugar composition (A) and glycaemic response (B) of common sweeteners. Sugar composition data represents the typical contribution of glucose, fructose and sucrose to the total sugar contents of various sweeteners (data retrieved using Nutritics© software 2014, available online: https://www.nutritics.com/p/home). Glycaemic index (GI) data are mean values with error bars showing standard error of the mean from human studies as reported in the University of Sydney GI database (University of Sydney, 2015).

density (typically 250–310 kcal per 100 g wet weight) is lower compared with lower moisture (<1%) solid sweeteners, which typically contain 380–390 kcal per 100 g wet weight (see Table 2). Consequently, substituting sucrose (i.e. table sugar) with an equal weight of liquid sweetener could, in theory, provide a means of lowering energy intake. The effectiveness of this in practice however is uncertain since it will depend on how consumers use various sugar substitutes (e.g., with regard to the amounts added, and frequency of use).

Traditional sweeteners contain additional nutritive compounds that are excluded from refined NS (e.g., table sugar, HFCS) or pure NNS. The exact nutrient composition of natural products is known to vary, but typically traditional sweeteners contain proteins (<1.4%), lipids (<0.5%), dietary fibre (<3%), and phytochemicals such as polyphenols (Table 2) (Ozcan, Arslan, & Gokcalik, 2007). Small amounts of minerals (<2%; mostly potassium, calcium, magnesium, manganese and phosphorous), and vitamins (<0.02%; i.e., including vitamins A, B_1, B_2, B_3, B_6, B_{12}, C, E, K) may also be present, but the contribution of natural sweeteners to meeting daily vitamin/mineral requirements would be regarded as negligible when consumed in limited amounts as part of a healthy diet.

5.1. Glycaemic potency

Some of the traditional sweeteners, such as honey, agave and carob, have a lower glycaemic potency (Deibert, König, Kloock, Groenefeld, & Berg, 2010; St-Pierre et al., 2014; University of Sydney, 2015) than refined sugars (Fig. 2B) and may therefore appeal to those following a low glycaemic index (GI) diet (Jenkins et al., 2002). The low GI of these products may be attributed in part to their relatively high proportion of fructose, which has a particularly low GI of 19, compared with glucose (GI = 100) and sucrose (GI = 68) (Foster-Powell et al., 2002), In recent years, however, the increased consumption of HFCS (i.e., containing ~42 or 55% fructose and 53 or 42% glucose, respectively) has led to concerns that consumption of high-levels of fructose may have adverse effects on health (Bray, 2010). It is well established that fructose is metabolised differently from glucose in the liver. When excess fructose from the diet accumulates, it promotes hepatic *de novo* lipogenesis, thereby increasing the risk of hypertriacylglycerolaemia (Havel, 2005). A range of human studies have shown that high intakes of fructose, at doses contributing more than 15% of total dietary energy, lead to hyperlipidaemia - a risk factor for cardiovascular disease (see review by Havel, 2005). However, the relevance of these findings to a normal diet is debatable because of the high doses used, which are typically 1.5 to 3 times higher than the 95th percentile level of intake (White, 2013). When consumed at more realistic levels, fructose has not been shown to cause clinically significant changes in serum triacylglycerol concentrations (Dolan, Potter, & Burdock, 2010). Furthermore, many studies have examined the metabolic effects of pure fructose administration, even though it is rarely consumed in this form in the diet. Fructose is normally obtained from sources, such as HFCS or fruit, where it coexists with glucose. Therefore, in the context of a normal diet (or indeed, a low-GI diet) the inclusion of fructose-rich foods does not appear to pose any health concerns. It is noteworthy, however, that in specific patient populations such as those with irritable bowel syndrome or fructose malabsorption, the consumption of high proportions of fructose may have an osmotic effect in the large intestine leading to exacerbation of gastrointestinal symptoms (Staudacher, Irving, Lomer, & Whelan, 2014). In such cases other natural sweeteners with lower proportions of fructose, such as maple syrup, may provide a suitable alternative.

Although the presence of fructose in many traditional sweeteners may explain their relatively lower glycaemic potency compared with glucose-rich sweeteners (Fig. 2), there are some studies which suggest that the other components present within traditional sweeteners may contribute to an attenuation of glycaemia (Erejuwa et al., 2012a). The GI of some traditional sweeteners can in some instances be lower than might be expected based

Table 2
Typical nutrient and total phenolic composition of common traditional sweeteners.[1]

Component	Agave syrup	Honey	Molasses	Maple syrup	Carob syrup	HFCS	Sucrose
Energy (kcal/100 g)	310	304	290	260	248[a]	281	387
Water (g/100 g)	23	17	22	32	35[a]	24	0
Protein (g/100 g)	0.1	0.3	0.0	0.0	1.4[a]	0.0	0.0
Total lipid (g/100 g)	0.5	0.0	0.1	0.1	0.0[a]	0.0	0.0
Carbohydrate, by difference (g/100 g)	76.4	82.4	74.7	67.0	–	76.0	100.0
Fibre, total dietary (g/100 g)	0.2	0.2	0.0	0.0	3.3[a]	0.0	0.0
Sugars, total (g/100 g)	68.0	82.1	74.7	60.5	63.9[a]	75.7	99.8
Minerals (mg/100 g)							
Calcium, Ca	1	6	205	102	86[a]	0	1
Iron, Fe	0.09	0.42	4.72	0.11	1.10[a]	0.03	0.05
Magnesium, Mg	1	2	242	21	54[a]	0	0
Phosphorus, P	1	4	31	2	239[a]	0	0
Potassium, K	4	52	1464	212	1608[a]	0	2
Sodium, Na	4	4	37	12	113[a]	2	1
Zinc, Zn	0.01	0.22	0.29	1.47	–	0.02	0.01
Vitamins							
Vitamin C, 'Ascorbic acid' (mg/100 g)	17	0.5	0	0	–	0	0
Vitamin B_1 'Thiamin' (mg/100 g)	0.122	0	0.041	0.066	–	0	0
Vitamin B_2 'Riboflavin' (mg/100 g)	0.165	0.038	0.002	1.27	–	0.019	0.019
Vitamin B_3 'Niacin' (mg/100 g)	0.689	0.121	0.93	0.081	–	0	0
Vitamin B_6 'Pyridoxine' (mg/100 g)	0.234	0.024	0.67	0.002	–	0	0
Vitamin B_{12} 'Folate', (DFE μg/100 g)	30	2	0	0	–	0	0
Vitamin A, (RAE μg/100 g)	8	0	0	0	–	0	0
Vitamin E 'α-Tocopherol' (mg/100 g)	0.98	0	0	0	–	0	0
Vitamin K 'Phylloquinone' (μg/100 g)	22.5	0	0	0	–	0	0
Total polyphenolics (mg GAE/100 mL)	1.292[b]	1.935[b]	9.195[b]	1.494[b]	–	0.268[b]	–

[1] All data was obtained from the USDA database (2015) unless otherwise specified. [a] Data from Ozcan et al., 2007 and [b] St-Pierre et al., 2014. Total dietary fibre content was determined by enzymatic-gravimetric methods 985.29 or 991.43 of the AOAC. Abbreviations: GAE; gallic acid equivalents, HFCS; high fructose corn syrup, RAE; retinol activity equivalents.

on their sugar content. However, the marked variation in the composition of traditional sweeteners inevitably leads to a greater uncertainty in GI values for these sweeteners. Nevertheless, it is worth noting that the traditional sweeteners are known to contain a plethora of different phytochemical compounds *(see next section),* some of which have been shown to have anti-diabetic effects (Arts & Hollman, 2005; Erejuwa et al., 2012a; Scalbert, Johnson, & Saltmarsh, 2005). It is feasible therefore, that the presence of phytochemical compounds could contribute to a reduction in the glycaemic potency of traditional sweeteners compared with glucose syrup and sucrose. Further postprandial glycaemic and insulinaemic studies of traditional sweeteners are warranted to explore the suggested blood glucose-lowering effects of the phytochemicals present within these products.

5.2. Polyphenolic and related compounds

Traditional sweeteners such as maple syrup and honey contain a range of (poly) phenolic compounds including various flavonoids (e.g., quercetin, kaempferol, myricetin, proanthocyanidins, and 'condensed tannins'), and non-flavonoids such as phenolic acids (e.g., caffeic-, coumaric-, vanillic-, syringic-, hydroxybenzoic-acids), lignans (e.g. lariciresinol, secoisolariciresinol), coumarins and stilbenoids (Bogdanov et al., 2008; Li & Seeram, 2010; St-Pierre et al., 2014). Phytohormones, notably abscisic acid and its derivative phaseic acid, which play a role in regulating plant growth, dormancy and stress response, have also been detected in plant-derived sweeteners, particularly in maple syrup (St-Pierre et al., 2014). These compounds have a range of properties that could have a potential impact on nutrition and health. A diet rich in polyphenols may, for instance, be beneficial in reducing risk of cardiovascular disease, and may also have some potential in preventing neurodegenerative conditions and type 2 diabetes (Arts & Hollman, 2005; Scalbert et al., 2005). Indeed, extracts rich in polyphenolic compounds, including those found in natural sweeteners, are currently being investigated as potential pharmaceutical or therapeutic agents (Dai & Mumper, 2010). Although such compounds are thought to have a number of health benefits, the underlying mechanisms by which they may do so remain unclear (Alvarez-Suarez, Giampieri, & Battino, 2013).

Some researchers believe that anti-oxidant properties, i.e., the capacity to scavenge harmful reactive oxygen species, may hold the key to explaining the suspected health benefits of phenolic compounds. Therefore the relative anti-oxidant capacity of various phytochemical extracts and foods has been documented (Dai & Mumper, 2010; Erejuwa, Sulaiman, & Ab Wahab, 2012b; Phillips, Carlsen, & Blomhoff, 2009; Scalbert et al., 2005). It is clearly evident from laboratory studies that traditional sweeteners contain a range of compounds with anti-oxidant properties (Erejuwa et al., 2012b; Li & Seeram, 2010; Phillips et al., 2009). The relevance of *in vitro* antioxidant measurements for predicting effects on human health is doubtful, however, and regulatory bodies such as the European Food Safety Authority (EFSA) and the United States Department of Agriculture (USDA) do not recognise these *in vitro* methods as being reliable predictors of physiological activity. Thus, although the literature contains examples of studies where workers have extrapolated *in vitro* data to broader positive effects on disease protection/prevention *in vivo* (Erejuwa et al., 2012b, 2012a; Phillips et al., 2009), these inferences are probably premature. This is certainly an area where further research is needed to establish how and to what extent the antioxidant capacity of these compounds may impact on disease pathogenesis *in vivo*.

Another significant property of many polyphenolic compounds is that they interact with proteins, and therefore have the potential to influence biological targets such as enzymes, transcription factors, and receptors (Fraga, Galleano, Verstraeten, & Oteiza, 2010). For instance, as reviewed recently, flavanols seem to have benefits on cardiovascular health by modifying vascular parameters (e.g., inflammation-related markers, atherosclerosis and blood pressure), myocardial conditions (e.g., infarction) and whole body metabolism (De Pascual-Teresa, Moreno, & García-Viguera, 2010). Polyphenolic compounds may also influence the digestion, absorption and metabolism of available carbohydrates. For instance, a variety of polyphenolic compounds, such as flavonoids, phenolic acids and tannins, have been reported to limit digestion of starch through inhibition of α-amylase and/or α-glucosidase (Hanhineva et al., 2010). Some flavonoids (e.g., quercetin, myricetin) and phenolic acids (e.g., caffeic acid) have also been found to delay and/or prevent glucose absorption through inhibition of glucose transporters SGLT-1 and/or GLUT-2 (Hanhineva et al., 2010). Post-absorption, the presence of polyphenolic compounds or their metabolites may impact on metabolism, for instance, by enhancing pancreatic β-cell function and thereby insulin-stimulated glucose clearance in fat and muscle (Erejuwa et al., 2012a). Some argue that the presence of these and related compounds in traditional sweeteners may help to counteract the undesirable effects of the sugars on glycaemia and lipid metabolism. One study in rats reported that the hypertriacylglycerolaemic effects of fructose were not observed when honey was fed in place of refined carbohydrate. This animal study supports the view that traditional sweeteners may confer some protection against dyslipidaemia and oxidative stress, however the mechanisms and compounds responsible have not yet been identified (Busserolles, Gueux, Rock, Mazur, & Rayssiguier, 2002). An example of a beneficial compound that has recently received attention for its suspected anti-diabetic effects is pinitol - a cyclic polyol (3-*O*-methyl-D-chiro-inositol) which is found in carob syrup (7g/100g syrup) and is converted post-absorption to D-chiro-inositol (i.e., a second messenger in insulin-signal transduction) (Davis et al., 2000; Hernández-Mijares et al., 2013). Several human studies suggest that acute (Hernández-Mijares et al., 2013), and chronic administration (Kim et al., 2012) of moderate doses of pinitol (1–7 g/d) may be beneficial in reducing risk factors associated with diabetes (e.g., improving insulin sensitivity), although it should be pointed out that one other study observed no such effect (Campbell et al., 2004). Further human studies are needed to establish unequivocally whether dietary sources of pinitol and other related compounds can have long term benefits in different population/patient groups (e.g., people at risk to type 2 diabetes).

Overall, it is encouraging that so many different compounds have been identified in traditional sweeteners, but there is insufficient evidence to establish currently whether or not these compounds have any impact on human health, especially when consumed as part of a normal diet. Although a number of studies have reported beneficial effects of the compounds that also exist in traditional sweeteners, the dosages used in clinical studies are often in excess of what could be achieved through the use of these sweeteners in the normal diet. For example, in the US, the average daily intake of flavonoids is estimated to be 190 mg/d (Chun, Chung, & Song, 2007), so the contribution of traditional sweeteners such as honey, which typically contains 0.6–4.6 mg of flavonoids/100 g (Meda, Lamien, Romito, Millogo, & Nacoulma, 2005), to a typical diet would be relatively low. Nevertheless, it is not necessarily the total amount of phytochemicals consumed that is important, but rather their bioefficacy. This is another area where understanding is limited however, and calls for further investigation.

6. Future trends

The high prevalence of obesity is a major public health concern and a huge financial burden, with medical costs of obesity amounting to £2 billion in the UK in 2001 (Butland et al., 2007). It has been projected that if current trends continue, by 2050, over 50% of the UK population, will be classified as obese (Butland et al., 2007) and will be at an increased risk therefore of developing associated medical conditions such as heart disease, stroke, type 2 diabetes and mental illness. Irrespective of whether or not sugars have played a causal role in the obesity epidemic, the future use of sugars and sweeteners is likely to be influenced by the perceived nutritional requirements of an increasingly obese population.

Despite accusations that food and drink manufacturers add unnecessary amounts of sugars to food and beverages, the reduction of sugars in these products is by no means a trivial and straightforward matter. Food manufacturers will defend their practice of adding sugars to many food products because sugars are not just added to provide sweetness, but also serve other purposes; for instance, sugars are used as preservatives, bulking agents or for controlling texture (Shumow, 2015). Removing sugars from these products, while maintaining quality, would in many instances require the substitution of sugars by other compounds to replace their technological functions. Moreover, consumers have already developed a preference for sweet flavour, and, although a gradual 'unsweetening' of the diet may be beneficial, consumers are likely to resist changes in sweetness intensity and other sensory characteristics.

At present, there are various categories of alternative sweeteners available (*see overview in* Fig. 3.), but do these truly provide 'healthier' alternatives and would they be of any real benefit to an increasingly obese society? Intuitively, the NNS which provide sweet-taste, but no calories, seem like the ideal substitutes for glycaemic-sugars, and are therefore increasingly used by consumers wanting to achieve weight loss (Gardner et al., 2012; Mattes & Popkin, 2009; Ng et al., 2012). However, these presumed benefits of NNS are still not convincingly evidenced by the scientific literature. On the contrary, there are growing concerns that the lack of satiation and intense sweetness of NNS could result in subsequent compensatory energy intake and therefore weight gain. This critical issue threatens the fundamental efficacy of low-caloric products in aiding weight loss and urgently requires further investigation.

In view of populist consumer concerns about the safety of NNS, the use of traditional sweeteners, which have been safely consumed for centuries and preceded the obesity epidemic, may be more appealing to some. These sweeteners are caloric, but tend to have a lower glycaemic potency than their more refined counterparts. They also contain a range of interesting polyphenolic and related compounds, many of which may possess desirable biological properties. Although further studies are needed before any potential health benefit can be claimed, these sweeteners may already be of interest to manufacturers who wish to develop more 'natural' products.

While further research will continue to make progress in the area to understand the effect of various sweeteners on health, there are other means by which the food and drink industry can support public health initiatives. Suppliers and manufacturers can contribute to encouraging consumers to reduce their total energy intake through responsible advertising, increasing consumer education activities, and by providing clearer advice on sensible portion sizes and focusing on whole foods and diets rather than individual nutrients. Equally, the consumers must take some responsibility for their diet and lifestyle choices.

7. Conclusions

Despite the lack of consensus across the scientific literature regarding the role of sweet-tasting mono- and disaccharides in health, new guidelines, policies and taxes are being introduced at government level to encourage the reduction of added sugars in the diet. In response, manufacturers are expected to develop 'healthier' sweeteners. The use of artificial or high-potency sweeteners may help to reduce dietary energy intakes from NS, although their impact on rates of obesity is unclear. For some consumers and manufacturers, traditional sweeteners provide a preferable alternative to artificial or refined sources. In particular, most traditional sweeteners provide a lower GI than refined sugar sources as well as containing numerous additional nutrients and in some cases biologically-active phytochemicals that are absent in refined products. Many of these phytochemicals are anti-oxidants and/or appear to have the capacity to modify other physiological

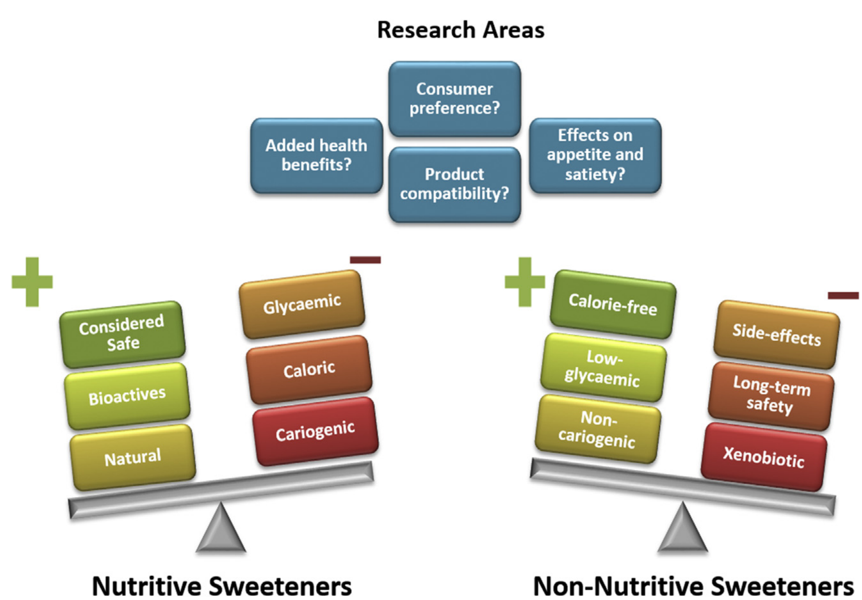

Fig. 3. Overview of nutritionally-relevant properties of nutritive and non-nutritive sweeteners. Effects that are viewed as potentially beneficial are shown in green and effects that are generally considered to be adverse are shown in red. There are advantages (+) and disadvantages (−) to both categories of sweeteners. Priority research areas that apply to all sweeteners are shown in blue. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

processes, with effects on postprandial metabolism (e.g., amelioration of glycaemic control), but their mechanisms of action are still not entirely clear. Although the jury is still out on defining precise health effects of these bioactive compounds, such compounds seem to be of great relevance to what constitutes a healthy diet, and further studies of their dietary properties are warranted. Overall, trends in sweetener use in the future will continue to be influenced by the obesity epidemic and therefore further research to determine whether NNS, NS or traditional sweeteners provide the best solution is encouraged.

Conflicts of interest

CHE was in receipt of funding from Clark's UK Ltd., who manufacture and supply traditional sweeteners, during the preparation of this article. The other authors have no conflict of interest.

Acknowledgements

The authors thank Byron Light and Bob Clark (Clark's UK Ltd., Newport, UK) for insightful discussions about processing and manufacture of maple syrup and other sweeteners and also for providing financial support for CHE.

References

Alvarez-Suarez, J. M., Giampieri, F., & Battino, M. (2013). Honey as a source of dietary antioxidants: Structures, bioavailability and evidence of protective effects against human chronic diseases. *Current Medicinal Chemistry, 20*, 621–638.
Arts, I. C., & Hollman, P. C. (2005). Polyphenols and disease risk in epidemiologic studies. *The American Journal of Clinical Nutrition, 81*, 317S–325S.
Bogdanov, S., Jurendic, T., Sieber, R., & Gallmann, P. (2008). Honey for nutrition and health: A review. *Journal of the American College of Nutrition, 27*, 677–689.
Bray, G. A. (2010). Fructose: Pure, white, and deadly? Fructose, by any other name, is a health hazard. *Journal of Diabetes Science and Technology, 4*, 1003–1007.
Busserolles, J., Gueux, E., Rock, E., Mazur, A., & Rayssiguier, Y. (2002). Substituting honey for refined carbohydrates protects rats from hypertriglyceridemic and prooxidative effects of fructose. *The Journal of Nutrition, 132*, 3379–3382.
Butland, B., Jebb, S., Kopelman, P., McPherson, K., Thomas, S., Mardell, J., et al. (2007). *Foresight. Tackling obesities: Future choices. Project report*. London: Government Office for Science.
Campbell, W. W., Haub, M. D., Fluckey, J. D., Ostlund, R. E., Jr., Thyfault, J. P., Morse-Carrithers, H., et al. (2004). Pinitol supplementation does not affect insulin-mediated glucose metabolism and muscle insulin receptor content and phosphorylation in older humans. *The Journal of Nutrition, 134*, 2998–3003.
Chattopadhyay, S., Raychaudhuri, U., & Chakraborty, R. (2014). Artificial sweeteners – A review. *Journal of Food Science and Technology, 51*, 611–621.
Chun, O. K., Chung, S. J., & Song, W. O. (2007). Estimated dietary flavonoid intake and major food sources of U.S. adults. *The Journal of Nutrition, 137*, 1244–1252.
Coultate, T. (2016). *Food- the chemistry of its components* (6th ed., pp. 303–304). Cambridge: Royal Society of Chemistry. See Table 7.1 – Relative sweetness of sugars and sugar alcohols.
Dai, J., & Mumper, R. J. (2010). Plant phenolics: Extraction, analysis and their antioxidant and anticancer properties. *Molecules, 15*, 7313–7352.
Davis, A., Christiansen, M., Horowitz, J. F., Klein, S., Hellerstein, M. K., & Ostlund, R. E., Jr. (2000). Effect of pinitol treatment on insulin action in subjects with insulin resistance. *Diabetes Care, 23*, 1000–1005.
De Pascual-Teresa, S., Moreno, D. A., & García-Viguera, C. (2010). Flavanols and anthocyanins in cardiovascular health: A review of current evidence. *International Journal of Molecular Sciences, 11*, 1679–1703.
Deibert, P., König, D., Kloock, B., Groenefeld, M., & Berg, A. (2010). Glycaemic and insulinaemic properties of some German honey varieties. *European Journal of Clinical Nutrition, 64*, 762–764.
Dolan, L. C., Potter, S. M., & Burdock, G. A. (2010). Evidence-based review on the effect of normal dietary consumption of fructose on blood lipids and body weight of overweight and obese individuals. *Critical Reviews in Food Science and Nutrition, 50*, 889–918.
Erejuwa, O. O., Sulaiman, S. A., & Ab Wahab, M. S. (2012a). Honey - A novel antidiabetic agent. *International Journal of Biological Sciences, 8*, 913–934.
Erejuwa, O. O., Sulaiman, S. A., & Ab Wahab, M. S. (2012b). Honey: A novel antioxidant. *Molecules, 17*, 4400–4423.
Ferreira, A. V., Generoso, S. V., & Teixeira, A. L. (2014). Do low-calorie drinks 'cheat' the enteral-brain axis? *Current Opinion in Clinical Nutrition and Metabolic Care, 17*, 465–470.
Foster-Powell, K., Holt, S. H., & Brand-Miller, J. C. (2002). International table of glycemic index and glycemic load values: 2002. *The American Journal of Clinical Nutrition, 76*, 5–56.
Fraga, C. G., Galleano, M., Verstraeten, S. V., & Oteiza, P. I. (2010). Basic biochemical mechanisms behind the health benefits of polyphenols. *Molecular Aspects of Medicine, 31*, 435–445.
Gardner, C., Wylie-Rosett, J., Gidding, S. S., Steffen, L. M., Johnson, R. K., Reader, D., et al. (2012). Nonnutritive sweeteners: Current use and health perspectives: A scientific statement from the American Heart Association and the American Diabetes Association. *Diabetes Care, 35*, 1798–1808.
Gwak, M.-J., Chung, S.-J., Kim, Y., & Lim, C. (2012). Relative sweetness and sensory characteristics of bulk and intense sweeteners. *Food Science and Biotechnology, 21*, 889–894.
Hanhineva, K., Törrönen, R., Bondia-Pons, I., Pekkinen, J., Kolehmainen, M., Mykkänen, H., et al. (2010). Impact of dietary polyphenols on carbohydrate metabolism. *International Journal of Molecular Sciences, 11*, 1365–1402.
Havel, P. J. (2005). Dietary fructose: Implications for dysregulation of energy homeostasis and lipid/carbohydrate metabolism. *Nutrition Reviews, 63*, 133–157.
Hernández-Mijares, A., Bañuls, C., Peris, J. E., Monzó, N., Jover, A., Bellod, L., et al. (2013). A single acute dose of pinitol from a naturally-occurring food ingredient decreases hyperglycaemia and circulating insulin levels in healthy subjects. *Food Chemistry, 141*, 1267–1272.
Jenkins, D. J., Kendall, C. W., Augustin, L. S., Franceschi, S., Hamidi, M., Marchie, A., et al. (2002). Glycemic index: Overview of implications in health and disease. *The American Journal of Clinical Nutrition, 76*, 266s–273s.
Johnson, R. J., Segal, M. S., Sautin, Y., Nakagawa, T., Feig, D. I., Kang, D.-H., et al. (2007). Potential role of sugar (fructose) in the epidemic of hypertension, obesity and the metabolic syndrome, diabetes, kidney disease, and cardiovascular disease. *The American Journal of Clinical Nutrition, 86*, 899–906.
Kahn, R., & Sievenpiper, J. L. (2014). Dietary sugar and body weight: Have we reached a crisis in the epidemic of obesity and diabetes?: We have, but the pox on sugar is overwrought and overworked. *Diabetes Care, 37*, 957–962.
Kim, H. J., Park, K. S., Lee, S. K., Min, K. W., Han, K. A., Kim, Y. K., et al. (2012). Effects of pinitol on glycemic control, insulin resistance and adipocytokine levels in patients with type 2 diabetes mellitus. *Annals of Nutrition and Metabolism, 60*, 1–5.
Levin, G. V., Zehner, L. R., Saunders, J. P., & Beadle, J. R. (1995). Sugar substitutes: Their energy values, bulk characteristics, and potential health benefits. *The American Journal of Clinical Nutrition, 62*, 1161S–1168S.
Li, L., & Seeram, N. P. (2010). Maple syrup phytochemicals include lignans, coumarins, a stilbene, and other previously unreported antioxidant phenolic compounds. *Journal of Agricultural & Food Chemistry, 58*, 11673–11679.
MacGregor, G. A., & Hashem, K. M. (2014). Action on sugar—lessons from UK salt reduction programme. *The Lancet, 383*, 929–931.
Mattes, R. D., & Popkin, B. M. (2009). Nonnutritive sweetener consumption in humans: Effects on appetite and food intake and their putative mechanisms. *The American Journal of Clinical Nutrition, 89*, 1–14.
Meda, A., Lamien, C. E., Romito, M., Millogo, J., & Nacoulma, O. G. (2005). Determination of the total phenolic, flavonoid and proline contents in Burkina Fasan honey, as well as their radical scavenging activity. *Food Chemistry, 91*, 571–577.
Mortensen, A. (2006). Sweeteners permitted in the European Union: Safety aspects. *Scandinavian Journal of Food & Nutrition, 50*, 104–116.
NDNS.. (2014). *National diet and nutrition Survey: Results from years 1 to 4 (combined) of the rolling programme for 2008 and 2009 to 2011 and 2012 [online]*. Available https://www.gov.uk/government/statistics/ Accessed 30.10.15.
Ng, S. W., Slining, M. M., & Popkin, B. M. (2012). Use of caloric and noncaloric sweeteners in US consumer packaged foods, 2005-2009. *Journal of the Academy of Nutrition and Dietetics, 112*, 1828–1834. e1826.
O'Brien-Nabors, L. (2011). *Alternative sweeteners* (4th ed.). Boca Raton: CRC Press.
Oppelt, S. A., Sennott, E. M., & Tolan, D. R. (2015). Aldolase-B knockout in mice phenocopies hereditary fructose intolerance in humans. *Molecular Genetics and Metabolism, 114*, 445–450.
Ozcan, M. M., Arslan, D., & Gokcalik, H. (2007). Some compositional properties and mineral contents of carob (Ceratonia siliqua) fruit, flour and syrup. *International Journal of Food Sciences and Nutrition, 58*, 652–658.
Phillips, K. M., Carlsen, M. H., & Blomhoff, R. (2009). Total antioxidant content of alternatives to refined sugar. *Journal of the American Dietetic Association, 109*, 64–71.
Scalbert, A., Johnson, I. T., & Saltmarsh, M. (2005). Polyphenols: Antioxidants and beyond. *The American Journal of Clinical Nutrition, 81*, 215S–217S.
Shumow, L. (2015). Sugars in confectionary products: Technical functions and links to health outcomes. In M. I. Goran, L. Tappy, & K.-A. Le (Eds.), *Dietary sugars and health* (pp. 43–58). Boca Raton, Florida: CRC Press.
St-Pierre, P., Pilon, G., Dumais, V., Dion, C., Dubois, M.-J., Dubé, P., et al. (2014). Comparative analysis of maple syrup to other natural sweeteners and evaluation of their metabolic responses in healthy rats. *Journal of Functional Foods, 11*, 460–471.
Staudacher, H. M., Irving, P. M., Lomer, M. C., & Whelan, K. (2014). Mechanisms and efficacy of dietary FODMAP restriction in IBS. *Nature Reviews: Gastroenterology and Hepatology, 11*, 256–266.
Suez, J., Korem, T., Zeevi, D., Zilberman-Schapira, G., Thaiss, C. A., Maza, O., et al. (2014). Artificial sweeteners induce glucose intolerance by altering the gut microbiota. *Nature, 514*, 181–186.
University of Sydney. (2015). *Glycaemic Index database [online]*. Available http://www.glycemicindex.com/index.php Accessed 30.10.15.
USDA.. (2015). *National nutrient database for standard reference release [online]*.

Available http://ndb.nal.usda.gov/ndb/foods/show/6278 Accessed 30.10.15.
White, J. S. (2013). Challenging the fructose hypothesis: New perspectives on fructose consumption and metabolism. *Advances in Nutrition: An International Review Journal, 4*, 246–256.
WHO Media Centre. (2015). *Factsheet: Obesity and overweight [online]*. Available http://www.who.int/mediacentre/factsheets/fs311/en/ Accessed 30.10.15.
WHO.. (2015). *Guideline: Sugar intakes for adults and children [online]*. Available http://apps.who.int/iris/ Accessed 20.10.15.
Yang, Q. (2010). Gain weight by "going diet?" Artificial sweeteners and the neurobiology of sugar cravings: Neuroscience 2010. *The Yale Journal of Biology and Medicine, 83*, 101–108.