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Is too much sugar bitter? The impacts of sugars on health

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This paper reviews the associations between sugars consumption and non-communicable diseases. Systematic reviews demonstrate associations between sugars intake and dental caries, weight gain, type 2 diabetes and cardiovascular diseases. Children consuming more sugar-sweetened beverages (SSBs) are 1.55 times more likely to be overweight. In adults, higher consumption of SSBs is associated with a 27% higher relative risk of developing type 2 diabetes. In adults, greater free sugar consumption was positively associated with total CVD (HR 1.07; 95% CI: 1.03–1.10), ischaemic heart disease (HR 1.06; 95%CI: 1.02,1.10), and stroke (HR 1.10, 95% CI: 1.04, 1.17). Those consuming sugars higher than the recommended level of 10% of total energy are more likely to develop dental caries; 42 out of 50 studies involving children and 5 out of 5 in adults reported at least one positive association between sugars and caries. Reduction in sugars consumption requires a myriad of interventions to reduce supply and demand at national and global levels, fiscal policies, alongside high-quality research and promoting environments to reduce the burden of NCDs.

Keywords*: sugars, dental caries, CVD, diabetes, obesity*

Introduction

The Nepalese saying 'Too much sugar is bitter' may hold some truth. The debate about the impact of sugars on health including dental caries, diabetes, obesity and heart disease began with Yudkin's seminal text in 1972 (Yudkin, 1972). His work faced considerable scepticism with the British Sugar Bureau and the World Sugar Research Organisation dismissing it as akin to science fiction (Meach, 2018). Forty years on, evidence has determined associations between sugars and non-communicable diseases (NCDs). In 2012, the World Health Organisation (WHO) commissioned two reviews: one assessing the impacts of sugars on dental caries, and one on the relationship between sugars and obesity. These reviews informed the WHO's guidelines on sugars intake (Te Mornega *et al*., 2013; Moynihan and Kelly 2014; WHO, 2015).

Non-communicable diseases have become the leading cause of mortality globally, accounting for 41 million (74%) of all deaths, with significant health inequalities disproportionately affecting those who are most disadvantaged (GBD, 2019). Although the causes of NCDs are multi-factorial, commercial determinants of health have exacerbated existing health inequalities (Friel *et al*., 2023).

Over the past 50 years, the consumption of sugars has increased worldwide, especially of sugar sweetened beverages (SSBs). Sugar consumption increases the risk of dental caries, the most prevalent NCD globally. In the UK, the number one reason for hospital admission for 6–10-year-olds is dental caries (PHE, 2021). Furthermore, excessive sugars consumption adds calories, leading to weight gain, thereby increasing the risk of type 2 diabetes and cardiovascular diseases (Gillespie *et al*., 2023). In 2015, three independent authorities, the WHO, the Scientific Advisory Committee on Nutrition (SACN) in the UK and the Dietary Guidelines Advisory Committee (DGAC) in the United States provided guidelines on sugar intake to alleviate the impacts of NCDs. The WHO recommends that adults and children consume free sugars to less than 10% total energy (E) intake and recommends a reduction to <5% energy for added health benefits.

Given the importance of this topic, the aim of this review is to summarise contemporary research on the relationships between sugars and NCDs.

Definition of sugars

The definition of sugars has been inconsistent. To establish a plausible association between a risk factor (sugar) and any given outcome, it is important to define the risk factor rigorously. A standardised definition of sugars now defines 'free sugars' as (WHO, 2015; SACN, 2015):

- monosaccharides (such as glucose, fructose) and
- disaccharides (such as sucrose or table sugar) that are added to food and drinks by the manufacturer, cook or consumer.
- sugars naturally present in honey, syrups, fruit juices and fruit juice concentrates.

An alternative classification defines 'added sugars' as sugars (monosaccharides and disaccharides) added to foods during processing or preparation (e.g., brown/white sugar, corn sweetener, corn syrup, dextrose, fructose, glucose, sucrose, high-fructose corn syrup, honey, lactose, maltose, malt syrup, molasses, raw sugar, and naturally occurring sugars that are isolated from a whole food e.g. fruit juice concentrates). The term excludes naturally occurring sugars present in intact fruit, vegetables, or dairy products or in juiced or pureed fruit and vegetables (Erickson and Slavin, 2015).

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Global sugars consumption

Global sugar consumption has been increasing and is expected to continue growing at approximately 1.4% per annum so that by 2030, this figure is expected to be at 196 million metric tons (OECD/FAO, 2021). A decline is anticipated in high income economies and a appreciable increase is expected in Asia and Africa.

Globally, children consume more free sugars as a proportion of total energy (%E) than adults (Walton *et al*., 2023). In the UK, children consume 8% more sugar than adults, while in the Netherlands and Belgium, the figures rise to 22% and 30%, respectively (Walton *et al*., 2023). Young people (11-17 years old) in Europe are the highest consumers of SSBs (Zucconi *et al*., 2013).

Evidence of the impacts of sugars on NCDs

Whilst there is a well-established relationship between dietary sugars and dental caries, the relationship between dietary sugars and NCDs is more complex. A recent umbrella review on this topic included 73 meta-analyses from 8601 publications and demonstrated negative impacts of sugars on several health outcomes including weight gain, cardiovascular outcomes, and dental caries (Huang *et al*., 2023). However, the evidence on SSBs and health outcomes was stronger than that for solid sugars. Consumption of SSBs leads to an increase in BMI, with a weighted mean difference of 0.85 (95% CI 0.50 to 1.20) when comparing the highest versus lowest intake of SSBs.

There are challenges in conducting research in this area. Although there have been numerous systematic reviews, not all of them have included randomised controlled trials, which may not always be feasible. Therefore, the quality of evidence may not meet this gold standard. Furthermore, most of the evidence has focused on intake of SSBs as one of the largest sources of free sugars. There are shortcomings in study design and divergent definitions of exposure (Prinz, 2019). In essence, this has compromised the quality and consistency of the available evidence (Johnson *et al*., 2009). One challenge is the measurement of sugar intake, which relies heavily on self-reports, which are prone to reporting bias. Sugar intake cannot always be captured in its totality including dose and frequency, resulting in heterogeneity between studies.

Sugars and Obesity

Globally, the prevalence of obesity has been increasing among adults and children for the past three decades with significant health inequalities. Examining trends across OECD countries in 2021 (Figure 1), 54% of the adult population were overweight or obese (OECD, 2023). For example, in the US and Mexico nearly 75% of adults were classified as overweight or obese, compared with just over 25% in Japan. The prevalence of childhood obesity also varies across 27 OECD countries (Inchley *et al*, 2020).

There are persistent inequalities in the prevalence of obesity and poor dietary behaviours, with those from lower socio-economic status to be more likely at risk (Mackenbach *et al*., 2008).

A systematic review of cohort studies and randomised controlled trials examined the associations between sugars and body weight separately in children and adults. Among adults, greater sugars consumption resulted in 0.75kg of weight gain (p<0.001) at follow-up in trials (Te Morenga *et al*., 2013), whereas lower sugars consumption reduced weight (-0.8kg, 95%CI: -1.21, -0.39). Findings from cohort studies showed similar trends, with 11 studies showing positive associations between sugars intake and anthropometric measures. In children, the association between sugars intake and weight gain was less consistent. Five trials evaluating sugars intake reduction in children failed to find an effect (Davis *et*

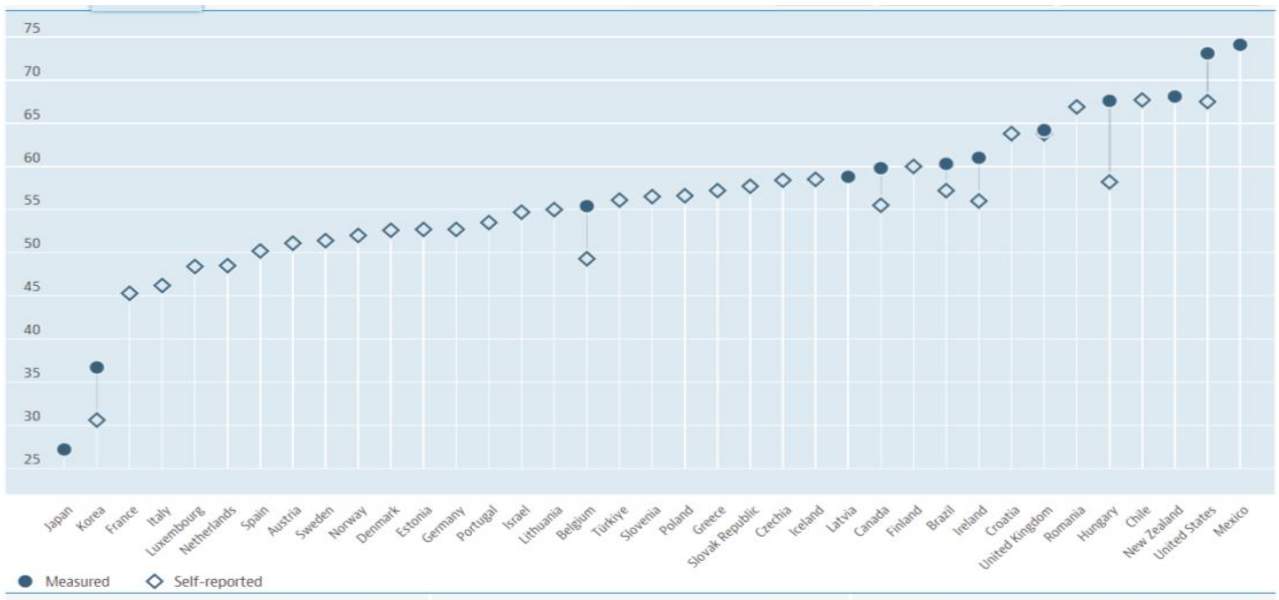

Figure 1. *Prevalence of overweight and obesity among adults (15 years and over) in OECD countries in 2022 (OECD (2023).*

al., 2009; Ebbeling *et al*., 2006; James *et al*., 2004; Paineau *et al*., 2008; Sichieri *et al*., 2009). The reasons for this could reflect children's poor adherence to diet advice and the trials being longer in duration than those for adults. However, this systematic review was rigorous in using the GRADE system for assessing the strength of the evidence.

There is more robust evidence on associations between consumption of SSBs and weight gain. Meta-analysis of five cohort studies, showed that children with high intakes of SSBs were 1.55 times (95% CI: 1.32, 1.82) more likely to be overweight or obese than children with a lower intake (Malik *et al*., 2013). Trials involving adults demonstrated that with increased intake of SSB resulted in increases in body weight between control and intervention (Weighted mean difference: 0.85; 95% CI: 0.50, 1.20).

A more recent systematic review of cohort and RCTs determining the associations between SSBs and weight gain included 85 articles (40 cohorts and 8 RCTs in children and 21 cohorts, and 16 RCTs in adults) (Nguyen *et al*., 2023). Each serving/day increase in SSB consumption was associated with 0.07kg/m^2 (95% CI: 0.04kg/m^2, 0.10 kg/m^2) in children and 0.42kg (95% CI: 0.26 kg, 0.58 kg) higher body weight in adults. Furthermore, there was a positive linear dose–response relationship between SSB intake and weight gain in cohort studies in both children and adults and in RCTs in adults. This was consistent with previous studies (Malik *et al*., 2013; Luger *et al.*, 2017). However, the authors acknowledged significant heterogeneity, which could not be explained by subgroup or sensitivity analysis.

Consumption of SSBs is common and is regarded as a contributor to the epidemic of obesity because SSBs' high sugar content, low satiety, high glycaemic load and incomplete compensation for total energy (Dell-Valle *et al*., 2005). SSBs may encourage greater energy intake leading to excessive weight gain, as sugar is less satiating when in liquid rather than solid form (Sunborn *et al*., 2019). Therefore, liquid calories can contribute to overconsumption, as liquids can be consumed quickly and may not register as fully in the body's satiety signals. (DiMeglio, and Mattes, 2000).

The totality of the evidence from experimental and observational studies demonstrates that sugars intake contributes to greater energy intake, thereby disrupting energy balance leading to the risk of weight gain. However, gaps in knowledge persist on the exact physiological mechanisms and the interaction with the environment that cause weight gain (Foresight, 2007).

Sugars and Type 2 Diabetes

Globally, the number of adults with diabetes rose from 108 million in 1980 to 476.0 million in 2017 (GBD, 2021) with commensurate rises in risk of mortality and morbidity. In 2021, there were an estimated 529 million people living with diabetes globally, projected to double to 1·31 billion by 2050. The main risk factor for type 2 diabetes is related to higher BMI.

SSBs provide the most consistent and significant dietary factor associated with type 2 diabetes in large epidemiological studies. Reduction in SSB intake is one of several cost-effective strategies in the prevention and management of diabetes. A meta-analysis of cohort studies found that with every daily additional serving of SSB, the relative risk increased by 27% (95%CI: 1.15, 1.41), 13% (1.03,1.25) for Type 2 diabetes and 9% (1.07, 1.12) and 8% (1.04, 1.11) for CVD (Meng *et al*., 2021). Again, these findings are consistent with other studies (Imamura *et al*., 2015; Qin *et al*., 2020; Santos *et al*., 2022).

Sugars and Cardiovascular Diseases

Globally, cardiovascular diseases resulted in 17.9 million deaths in 2019, affecting mainly low and middle income countries, contributing to 32% of all global deaths (WHO, 2021). Risk factors include high blood pressure, obesity, smoking, excessive alcohol consumption, diabetes and sedentary lifestyles.

The evidence on the relationship between free sugars and CVD has been inconsistent, mainly derived from cohort studies. A systematic review of 24 prospective cohort studies (Khan *et al*., 2019), which included 11,856 CVD incidence and 12,224 CVD mortality cases found no association between total sugars intake and incidence, but a positive association with CVD mortality (risk ratio, 1.09 (95%CI: 1.02, 1.17).

The relationship between sugars intake and CVD may depend on the type and quality of sugars, which may explain the variability in relationships. A recent study explored the associations between different types of free sugars and incidence of CVD in a large, population cohort of 110,497 UK Biobank participants (Kelly *et al*., 2023). Free sugars consumption was positively associated with total CVD (HR 1.07; 95% CI: 1.03–1.10), ischaemic heart disease (HR 1.06; 95%CI: 1.02,1.10), and stroke (HR 1.10, 95% CI: 1.04, 1.17).

A separate study using the same biobank data found that the intake of free sugars in solids, with the lowest hazard ratio occurring at 7% E (energy) (Schaefer *et al*., 2024). However, a linear correlation with CVD risk was demonstrated in relation to SSBs, reaching the HR at 3%E i.e. as the proportion of energy intake from SSBs increases, there's a corresponding increase in CVD risk. This is in line with other studies (Janzi *et al*., 2020).

Sugars and Dental Caries

Dental caries is the most prevalent chronic disease across the lifecourse, with untreated disease in the permanent dentition impacting on 2 billion individuals and 514 million children globally (GBD, 2019). There are clear social gradients in disease experience and the resulting out of pocket payments for dental care varies widely between and within countries (Peres *et al*., 2019).

The most robust evidence on the detrimental effects of sugars intake originates from studies on dental caries. Research has consistently shown a strong association between sugar consumption and dental caries risk across various populations and age groups (Moynihan and Kelly 2013; Valenzuela *et al*., 2021; Moss *et al*., 2022). High intake of free and added sugars and sugars naturally present in honey, syrups, fruit juices, and fruit concentrates are significant risk factors for the development of dental caries.

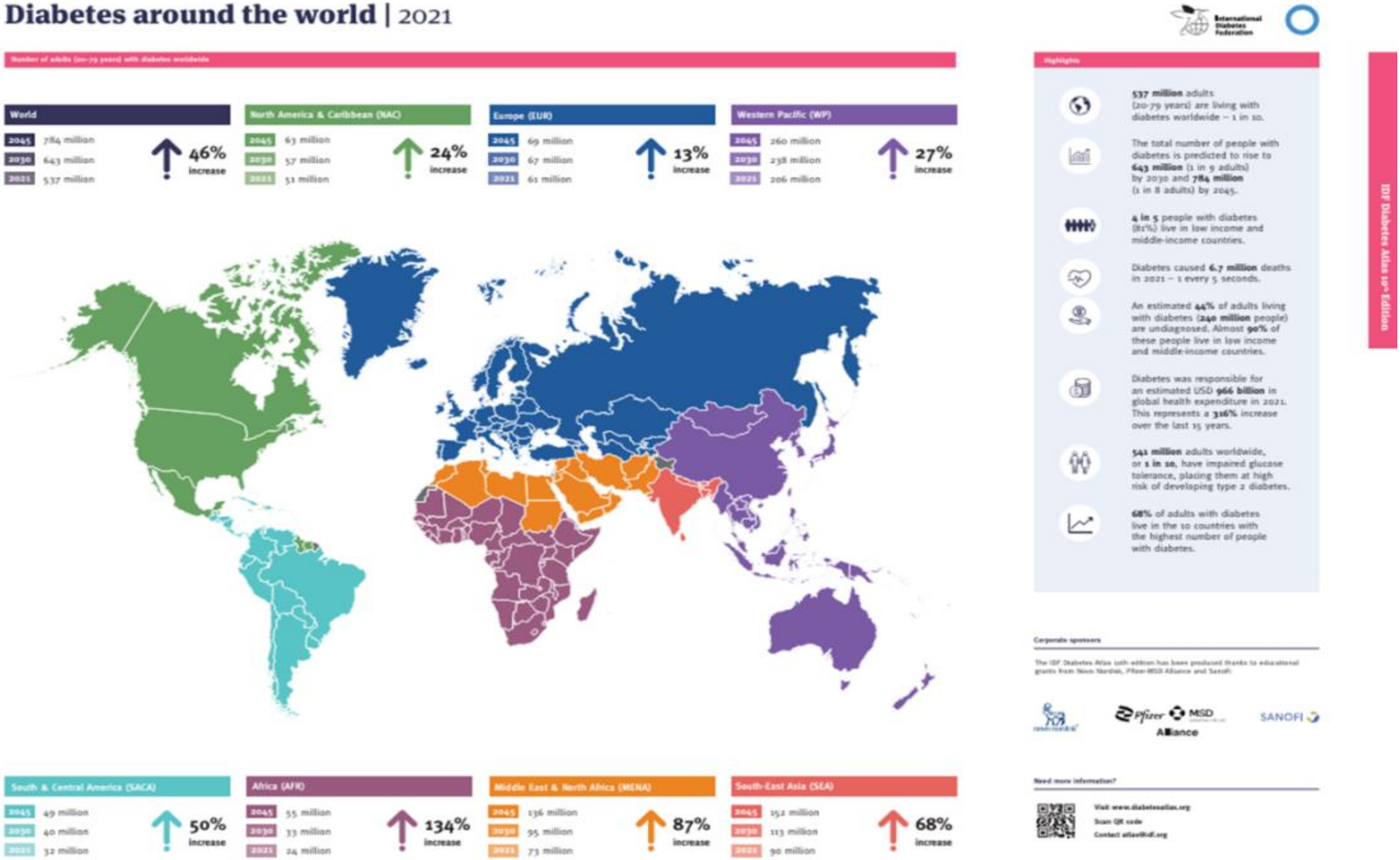

Figure 2. *Global prevalence of diabetes (source: IDF Diabetes Atlas).*

A systematic review, which largely informed the WHO guidelines on sugars intake explored their effects on dental caries (Moynihan and Kelly, 2014). The review included 55 studies (3 intervention, 8 cohort, 20 population, and 24 cross-sectional studies). A large effect size was detected in relation to the effect of sugars consumption on dental caries (standardised mean difference for DMFT 0.82, 95% CI: 0.67, 0.97). Consistency in the evidence, which was of moderate quality showed an association between sugars consumption and the development of dental caries; a higher rate of caries was found in those consuming sugars higher than 10% of energy when compared with less than 10% of energy, for both primary and permanent dentitions.

Another systematic review that explored the impacts of SSBs on dental caries included 38 cross-sectional studies of which 26 were of high quality (Valenzuela *at al*., 2021). This study demonstrated a dose-response relationship; even moderate-to-low consumption of SSBs is associated with 57% higher risk of dental caries (OR 1.57, 95% CI: 1.28,1.92).

Discussion

Our lifestyle patterns have drastically changed in the past twenty years, shaped by longer working hours, less physical activity and the abundant availability of cheap and energy-dense and ultra-processed foods high in fat, sugars and salt. Sugars are now ubiquitous. They are 'hidden' in food including in baby food and drinks to encourage a sweet palate from a very young age (Boulton *et al*., 2016). This means that we may be unwittingly consuming food and drinks high in sugars. The consumption of sugars globally is above the WHO's recommended level of 10% of total energy intake (WHO, 2015).

It is evident that NCDs are leading causes of morbidity and mortality worldwide. What strategies could be effective in halting the rise in NCDs and tackling the commercial determinants of health? The WHO Global Action Plan on NCDs and the more recent Global Strategy on Oral Health (WHO, 2013; WHO 2022) include early intervention and creating healthy public policies that tackle the underlying social and commercial determinants. A multi-sectoral approach involving different governmental sectors (business, agriculture, trade, education, health etc.) and civil society is required to ensure that private enterprises are promoting rather than harming our health (Friel *at al*., 2023).

There are lessons learnt from the WHO Framework Convention on Tobacco Control (WHO, 2003) despite some limitations in its implementation in low and middle-income countries. International and regional trade policy agreements are imperative in intervening at the root of the sugar supply chain, by influencing legislative and fiscal measures to reduce the demand and supply of sugars. Sugar is produced by developing and developed countries. Brazil is the largest producer globally and spends around $2.5 billion on sugar subsidies, whereas the EU is the third largest and also subsidizes sugar production. Therefore, a global solution would be to eliminate sugar subsidies with support from the World Trade Organisation. However, this complex network is influenced by profits and trade agreements nationally and globally. The 'big 10 food brands' including Associated British Foods (ABF), Coca-Cola, Danone, General Mills, Kellogg, Mars, Mondelez International, Nestlé, PepsiCo, and Unilever have a turnover of over $1.1bn per day (Oxfam, 2013). Using legislative and fiscal measures, the food industry should be actively involved in food reformulation and substitution.

Taxation is another potential solution to sugar reduction. Taxation on sugars has mainly focused on SSBs with varying rates, currently implemented in over 85 countries (WHO, 2022[2]). However, this could be expanded further to include juices, milk-based products, and sugary food. Mexico for example, introduced a 10% tax on SSBs in 2014, which has led to a 12% reduction in sales, with the largest impact on those from lower socio-economic groups (Colchero *et al*., 2015). Although there has been a noted decrease in the consumption of taxed sugar-added foods and drinks, there have been limited studies tracking taxation to health outcomes (Pfinder *et al*., 2020). An observational study in Mexico demonstrated a lower risk of dental caries (Hernandez *et al*., 2021) and another showed a lower risk of excess weight among adolescent girls where the taxation rate was higher than 10% (Gracner *et al*., 2022). Other interventions such as front pack-labelling has been implemented in Latin America, which led to a reduction in sugar sales (Taillie *et al*., 2021).

Communities and civic groups can be empowered to raise awareness on the detrimental effects of sugars to influence wider society and hold governments and food businesses to account. This needs to be accompanied by educating the future health workforce to advocate for public health (Institute of Health Equity, 2013). Health professionals could opportunistically deliver brief interventions and be involved in community engagement, both of which are in their infancy.

Researchers and public health experts need to ensure their work is not influenced or funded inappropriately by the sugar industry. Historically, the food industry has funded research across the globe and findings from research may be influenced by commercial incentives rather than by scientific evidence (Gornall, 2015).

Changing public policy can only be achieved with political prowess and mobilising public opinion on the impact of sugars on health with bold and evidence-based actions. This would not only halt the rising burden of NCDs, but also help to build a healthy environment for current and future generations.

Disclosure Statement

There is no conflict of interest.

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