An Evaluation of the Current Strategies Employed in Reducing the Sugar Content of Cakes

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By

Niamh Dowling (B.Sc.)

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Elizabeth Russell

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Declaration

I hereby certify that the material, which I now submit for assessment on the programme of study leading to the award of M.Sc., is entirely my own work and has not been taken from the work of others save to the extent that such work has been cited and acknowledged within the text of my own work. No portion of work contained in this thesis has been submitted in support of an application for another degree or qualification to this or any other institution.

Signed: Niamh Dowling Date: 24 April 2023

Niamh Dowling

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Abstract

Prevalence of non-communicable diseases is increasing globally. With incidence of overweight and obesity continuing to increase in Ireland, the government has launched a voluntary food reformulation framework to encourage the food industry to take responsibility for the nutritional status of the food supply. The Department of Health aims to achieve a 20% reduction in sugar in cakes by 2025, however it is recognised that sugar plays an important role in the physical and sensory attributes of cakes. Results from studies analysed in this thesis strongly demonstrate that food additives and sourdough technologies may help replace the functionalities of sugar, in sugar-reduced cakes. Results from the nutritional analysis of 234 cakes in Ireland, show that cakes still contain large amounts of sugar per 100g. Results also show that manufacturers are not using nutrition claims, which may help their product stand out from competitors. Further work is needed to assess the overall cost and efficiencies of using food additives and sourdough to reduce the sugar content of cakes.

List of Abbreviations

BMI	Body Mass Index
DoH	Department of Health
EU	European Union
FSA	Food Standards Agency
FSAI	Food Safety Authority of Ireland
FOP	Front of Pack
HFCS	High-fructose corn syrup
HSE	Health Service Executive
IUNA	Irish University Nutrition Alliance
NANS	National Adult Nutrition Survey
NCD	Non-communicable disease
NGO	Non-governmental organisation
NHS	National Health Service
NI	Northern Ireland
OHIP	Office for Health Improvement and Disparities
PHE	Public Health England
PKU	Phenylketonuria
ROI	Republic of Ireland
SACN	Scientific Advisory Committee on Nutrition
SKU	Stock Keeping Unit
UK	United Kingdom
WHO	World Health Organisation

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Chapter 1: Introduction

The focus of this thesis is to critically evaluate the current strategies employed in overcoming the challenges faced by manufacturers and retailers when reducing the sugar content of their cake products in order to meet voluntary reformulation targets set by the Department of Health (DoH). This thesis will define the concept of sugar reduction in cakes and evaluate a number of ingredients in terms of replacing the functions of sugar. This thesis will also examine the sugar content of cakes currently on the Irish market, along with assessing the use of nutrition claims. This introductory chapter will provide an overview of the epidemiological impact of overweight and obesity and the role of food reformulation in addressing the prevalence of overweight and obesity across the population.

1.1 Epidemiological impact of overweight and obesity

The prevalence of overweight and obesity is becoming more widespread across first-world countries, with the incidence of non-communicable diseases (NCDs) subsequently increasing (WHO, 2022b). The World Health Organisation (WHO) defines overweight and obesity as an unusual or excessive build-up of fat which can negatively affect a person's health status (WHO, 2022a). Healthy Ireland (2019) estimates that approximately 61% of adults in the Republic of Ireland (ROI) are overweight or obese. In a report by WHO (2022b), when ROI was compared with 53 other European Union (EU) member states, ROI was found to have a high prevalence of overweight and obesity across all age groups, with the country ranking ninth for incidence of obesity in adults. Table 1.1 outlines the results for incidence of overweight and obesity across specific Irish age groups measured by WHO (2022b).

Age group	**Ranking**
Adults	11
Children and adolescents (aged 10-19)	10
Children (aged 5-9)	9

Table 1.1. The ranking of Ireland with regard to prevalence of overweight and obesity, when compared with 52 member states (adapted from data by WHO, 2022b).

It is estimated that overweight and obesity is one of the main risk factors for developing NCDs or chronic diseases in conjunction with other genetic, behavioural, physiological or environmental factors (WHO, 2022a). The main types of NCDs include cardiovascular disease, such as stroke and heart attack, cancer, musculoskeletal diseases, such as osteoarthritis, and diabetes (WHO, 2022a). The WHO launched the Global Action Plan for the Prevention and Control of NCDs and set a global voluntary target to halt diabetes and obesity. This target was set to encourage a number of developed countries to introduce government policies to tackle overweight and obesity in their population (WHO, 2013). The WHO has since extended the Global Action Plan for the Prevention and Control of NCDs 2013-2020 to 2030 in response to the reported rapid rise of NCDs in low-income countries (WHO, 2022a).

In 2009, it was estimated that the direct and indirect costs of overweight and obesity on the Irish government amounted to €1.13 billion (Safefood, 2017). In 2016, the Irish government launched A Healthy Weight for Ireland, Obesity Policy and Action Plan 2016-2025 (DoH, 2016). This Policy stemmed from the Healthy Ireland - A Framework for Improved Health and Wellbeing 2013-2025 (Healthy Ireland, 2019). With levels of overweight and obesity having doubled in ROI in the last 20 years, the Irish government published this Policy in a bid to improve the overall health status of people living in ROI. The aim of this Policy is to assist in reducing the overall prevalence of overweight and obesity across the Irish population and to reduce the burden of overweight and obesity on individuals and society. The Policy acknowledges that determinants of overweight and obesity are varied, and that no single sector is responsible for increasing levels. With this, the Policy takes a multi-sectoral approach in striving to reduce the incidence of overweight and obesity in ROI. The sectors targeted include Health, Education, Transport and Sport, Workplaces, Environment and Local Government, non-governmental organisations (NGOs), Children, and the Food Industry, which are illustrated in Figure 1.1.

Figure 1.1. The sectors targeted as having roles to play in the prevention of overweight and obesity (adapted from data by DoH, 2016).

Findings from the Healthy Ireland Survey and the Childhood Obesity Surveillance Initiative suggest that rates of overweight and obesity are stabilising in ROI (Mitchell *et al.,* 2020). Based on this, the Irish government has set a target for a decline in prevalence in overweight and obesity, with progress being reviewed every two years. The most recent review was published in November 2022 (DoH, 2022). This review concluded that levels of overweight and obesity have tapered off in school-aged children however these levels have continued to increase in school-aged children from lower socio-economic backgrounds. Overall, the review acknowledged that so far the Policy has not succeeded in reducing the prevalence of obesity but it was also noted that no other WHO European country has been able to achieve a reduction in the prevalence.

The latest Health Ireland Survey revealed that across the ROI population, 35% of people are actively trying to lose weight, with the most popular means of doing so being through increased exercise (76%), followed by eating fewer calories (52%) and eating or drinking less sugar (42%) (Healthy Ireland, 2021).

1.2 Food reformulation as a public health strategy

Food reformulation is an increasingly popular policy strategy that aims to tackle the prevalence of overweight and obesity by targeting the food supply (Kaldor, 2018). With this, the responsibility is placed on the manufacturer to produce healthier products for the general population rather than requiring the individual consumer to alter their behaviour in any way. In many countries, food reformulation is voluntary with the food industry being actively encouraged and supported to achieve set goals and targets surrounding reformulation (Kaldor, 2018). Reformulation can be defined as "changing the nutrient content of a processed food product to either reduce the content of negative nutrients such as sodium, saturated fat, trans fat or energy (kilojoules) or to increase the content of beneficial nutrients such as dietary fibre, wholegrains, fruit, vegetables, and unsaturated fats" (DoH, 2021). At present, despite calls from public health experts, no country or jurisdiction has brought in mandatory enforcement of limits on sugar in food (Kaldor, 2018). Voluntary reformulation strategies can pose a risk to successful achievement as not all food businesses will want to participate and risk losing their business to another business, however mandatory regulation can help bring about a 'level playing field' (Kaldor, 2018).

1.2.1 The reformulation roadmap for Ireland

In ROI, food reformulation has been identified as a priority action within the Obesity Policy and Action Plan. Under Step three of the Ten Steps Forward listed in the DoH Obesity Policy and Action Plan: "Secure appropriate support from the commercial sector to play its part in obesity prevention" with the priority action being to "agree food reformulation targets with the food industry" within the first year (DoH, 2016).

In December 2021, A Roadmap for Food Product Reformulation in Ireland was launched (DoH, 2021). The Roadmap sets out a framework for reformulation in ROI, and published targets for voluntary reformulation in ROI, which are summarised in Table 1.2.

Nutrient	**Target**
Salt	10% reduction in priority food categories
Sugar	20% reduction in priority food categories
Saturated Fat	10% reduction in priority food categories
Energy (Kilocalories)	20% reduction in priority food categories

Table 1.2. Nutrients and agreed voluntary targets for reformulation as set out in A Roadmap for Food Product Reformulation in Ireland (adapted from data by DoH, 2021).

As part of this roadmap, a target has been agreed for a 20% reduction in the sugar content of nine priority food categories by 2025. Those priority food categories include: yogurts and fromage frais, biscuits, cakes mornings goods (e.g. pastries and buns), puddings, ice cream, lollies and sorbets, breakfast cereals, sweet confectionery, chocolate confectionery, and sweets spreads and sauces. These food categories were identified as being the main contributors to sugar intake in Ireland based on dietary intake surveys carried out by Irish University Nutrition Alliance (IUNA). These categories also mirror the food categories identified as targeted product categories for sugar reduction in Public Health England's (PHE) Sugar Reduction and Wider Reformulation Programme (DoH, 2016).

1.2.2 Reformulation strategies in other countries

The Irish reformulation roadmap closely aligns to food reformulation frameworks in place across the United Kingdom (UK) and the EU (DoH, 2021). Reformulation initiatives in these markets have been underway for some time.

1.2.2.1 Reformulation in Europe

Across Europe, countries have put in place strategies to tackle the increasing rates of overweight and obesity across their populations (Belc *et al.*, 2019). Each EU member state is responsible for developing their own policies to tackle overweight and obesity, and deciding on whether or not to put in place food reformulation frameworks (Belc *et al.,* 2019).

In a systematic review of the existing reformulation strategies in EU Member States, Switzerland, Norway and the UK, the researchers found that as of January 2019, 23 countries had implemented a reformulation framework (Kleis, Schulte and Buyken, 2020). The information in Table 1.3 details the results of these reformulation strategies. France and Italy saw decreases in the sugar content of soft drinks. In the Netherlands, there was limited data available of sugar reduction however there was not enough evidence to suggest efforts to reduce sugar were successful. Between 2016 and 2017, Switzerland reported that new product launches of breakfast cereals saw a sugar reduction of 5% while new yoghurts to the market saw a decrease of 3%. The UK saw an overall decrease of sugar content of 2%, and reported to be successful in 5 out of 8 priority food categories, however cakes and morning goods were excluded from this analysis as insufficient data was available.

Country	**Results**
France	Between 2008 and 2013: ● Breakfast cereals: 1% increase in sugar. ● Soft drinks: 2% decrease in sugar.
Italy	Between 2008 and 2014: ● Breakfast cereals: 6% decrease in sugar. ● Biscuits: 6% decrease in sugar. ● Soft drinks: 6% decrease in sugar until 2012.

Netherlands	Between 2011 and 2016: ● All product groups: Sugar content was consistent. Between 2014 and 2018: ● Milk drinks and milk desserts: 5% decrease in added sugar.
Switzerland	Between 2016 and 2017: ● New yoghurt and breakfast cereal products to the market had lower sugar content. ○ Yoghurts: 3% decrease. ○ Breakfast cereals: 5% decrease.
UK	Between 2015 and 2017: ● 2% decrease in sugar. ● Successful sugar reduction in 5 out of 8 food categories.

Table 1.3. The progress of sugar reduction reformulation efforts in some EU member states, Switzerland and the United Kingdom (UK) (adapted from data within Kleis, Schulte and Buyken, 2020).

1.2.2.2 Reformulation in the United Kingdom

In a report by the Scientific Advisory Committee on Nutrition (SACN) which examined the relationship between carbohydrates and health, it was concluded that the risk of becoming overweight or obese could be lowered by reducing sugar consumption (SACN, 2015). Following on from this report, PHE carried out a review of the interventions which could help reduce sugar across the UK population which led to the launch of the Sugar Reduction Programme in 2016 (PHE, 2016). As part of this Programme, the UK government set voluntary reformulation targets in a bid to reduce the sugar content of key food categories. The targets agreed were for the food industry to reduce sugar by 5% in the key food categories by 2018, and by 20% by 2020 (PHE, 2018). In an initial progress report by PHE (2018), it was determined that by the end of 2018, an overall 2% reduction in sugar content per 100g was observed. However in the final progress report, PHE, who has been renamed as the Office for Health

Improvement and Disparities (OHID), it was reported that between 2017 and 2020, there was a -3.2% change in the sales weighted average sugar per 100g for cakes from retailers and manufacturers (OHID, 2022).

1.3 Physiological and epidemiological impact of sugar

Research suggests that excessive consumption of sugar and fructose-enriched sweeteners, such as high-fructose corn syrup (HFCS), can be hazardous to human health (Mooradian, Smith, & Tokuda, 2017). Dietary sugars typically refer to monosaccharides (glucose, fructose, galactose), disaccharides (sucrose, maltose and lactose) and syrups, including HFCS (Ruxton, Gardner and McNulty, 2010). The term "free sugars" refers to any sugar added to food and drinks but also includes naturally-occurring sugars such as those present in honey, syrups, nectars and unsweetened fruit and vegetable purées (NHS, 2020). It is widely recognised that over-consumption of dietary sugars can be detrimental to human health. Sugar is associated with increased risk of metabolic syndrome, cardiovascular disease and diabetes mellitus (Mooradian, Smith & Tokuda, 2017). It is believed that the likelihood of developing type 2 diabetes mellitus is increased in those who consume an excess of dietary sugars and those with excess body fat (Veit *et al.,* 2022). The WHO published guidelines in relation to sugar intake and recommended that, in adults and children, their intake of free sugars should not be any more than 10% of their total calorific energy intake (WHO, 2015).

Freeman *et al.* (2018) carried out a review exploring the physiological effects of sugar on the body and brain. In their review, they looked primarily at table sugar (sucrose) and HFCS (which consists of 42% or 55% fructose and the remainder consisting of glucose). They found that foods which are high in sugar can trigger a reward response in which dopamine is released and this can lead to overeating beyond the energy requirements of these types of foods. The researchers discussed the notion that sugar on its own will not lead to obesity however sugar and fat combined can increase a person's chances of weight gain thus why highly-processed foods which typically

contain higher levels of sugar and fat tend to over-eaten, for example ice-cream and pizza.

According to a Healthy Ireland survey carried out between 2017 and 2018, consumption of unhealthy foods (which included cakes, biscuits, sweets, salted snacks and takeaways) was measured. It was found that 34% of people eat at least one of these foods on a daily basis, while 91% eat at least one per week. It was reported that 9% of people never eat these types of foods.

A National Adult Nutrition Survey (NANS) of adults in ROI (n=1500) was conducted by IUNA from 2008 to 2010. The consumption figures (g per day) for Irish adults of cakes, pastries and buns are detailed in Table 1.4. The highest consumption of cakes, pastries and buns was reported amongst males aged between 51 and 64 years, with a mean daily intake of 26g. While the lowest consumption was reported amongst females aged between 18 and 35 years, with a mean daily intake of 10g per day, and a median value of 0g per day which would indicate at least half of females aged between 18 and 35 years, who responded to the survey, consumed 0g per day.

Population Group	**Mean**	**SD**	**Median**
Adults (18-64y)	17	29	0
Males (18-64y)	18	32	0
Females (18-64y)	15	24	0
Males (18-35y)	14	31	0
Males (36-50y)	17	27	0
Males (51-64y)	26	39	10
Females (18-35y)	10	19	0

Females (36-50y)	16	25	0
Females (51-64y)	22	30	10
Adults (≥65y)	20	32	0
Males (≥65y)	24	37	8
Females (≥65y)	16	26	0

Table 1.4. Descriptive values for food intake (g/day) of cakes, pastries and buns, in Irish adults (n=1500) (adapted from data within IUNA, 2011).

Chapter 2: Functionality of Sugar and Sugar Replacers in Cakes

2.1 The composition of cakes

In their Sugar Reduction and Wider Reformulation Programme, the OHID identified cakes as a target product category for sugar reformulation (PHE, 2018). The OHID described cakes as all types of cakes, ambient and chilled, including cake bars and slices (PHE, 2018). While in another study, cakes were differentiated to products such as biscuits, due to the addition of eggs in the formulation (Van der Sman and Renzetti, 2020).

Generally speaking, there are two basic types of cakes; (i) shortened or high-ratio cakes and (ii) sponge cakes (Van der Sman and Renzetti, 2020). Shortened cakes are typically composed of wheat flour, sugar, egg and shortening, which are added at a 1:1:1:1 ratio (Deleu *et al*., 2016). Sponge cakes are typically composed of wheat flour, sugar and egg, added at a ratio of 1:1:1 (Godefroidt *et al.*, 2019). Some ingredients act as toughenners in cakes whereby they contribute to the building of the cake's protein network. Toughenners can include flour, egg white, milk solids and salt. Other ingredients may act as tenderisers, thereby hindering the protein network, with some examples of tenderisers including sugar, shortening and egg yolk (Mizukoshi., 1985).

2.2 The role of sugar in cakes

Sugar plays a key role in the manufacture of cakes. Sugar adds sweetness to a cake as well as contributing towards the colour of a cake. In a paper by Van der Sman and Renzetti (2020) which reviewed the functionality of sugar in cakes, it was concluded that sugar has an important part to play during both the mixing and baking stages of cake making. The researchers found that sugar acts as a humectant in cakes due to its hygroscopic properties and adds to the water activity of cakes.

There are two stages of cake making; mixing and baking (van der Sman and Renzetti, 2020). In the mixing stage of shortened cakes, the initial step is creaming whereby fat and sugar are mixed together with a whisk to incorporate air into the mixture. The fat and sugar are responsible for stabilising the air bubbles. The next step involves the addition of egg, while the last step involves the addition of flour. In the mixing stage of

foam cakes, the first step usually involves whisking egg white with sugar to create a meringue-like foam. This helps to aerate the mixture and aid increase the viscosity. After this, flour and sometimes egg yolk are added to the mixture. Egg yolk is a source of lecithin and can help emulsify and stabilise the egg white and sugar foam.

Reference	**Role of sugar**	**End-product effect**
Cauvain and Young, 2006b	Stabilisation of air-fat-foam	Increased volume
Clemens *et al.*, 2016	Enables gas-holding capacity of batter	
Frazier, 2009	Contributes to Maillard reaction	Browning and caramelisation
Struck *et al.*, 2014	Retention of moisture	Softer crumb

Table 2.1. The role of sugar in cakes and muffins and its effect on the end-product (adapted from data within Sahin *et al*., 2019).

Sahin *et al.* (2019) assessed the role that sugar plays in cakes and muffins and how this impacts on the end-product, with the findings listed in Table 2.1. According to these findings, sugar plays a role in stabilisation of air-fat-foam and enables gas-holding capacity of batter which results in increased specific volume in the end product. Sugar also contributes to the Maillard reaction which is responsible for browning and caramelisation of cakes, which is important for the appearance and flavour of the cake. Lastly, sugar plays a role in retention of moisture which is important for creating a softer crumb structure.

In a study by Van der Sman and Renzetti (2020), the researchers critically evaluated the role of sugar in the manufacture of cakes. Table 2.2 summarises the functionality of sugar during the processing of cakes, as well as listing its role on the final product. In the mixing stage, sugar is important as it adds air to the batter when it is in its crystalline

form. When sugar is dissolved, it enhances the viscosity of the batter which also helps to incorporate air into the batter as well as helping stabilise the foam, creating a uniform bubble structure throughout the batter. Lastly, sugar affects protein hydration during the mixing stage, as sugar is a hygroscopic ingredient and helps aid moisture retention.

Van der Sman and Renzetti (2020) also assessed the role of sugar during the baking and cooling stages, with the findings listed in Table 2.2. According to Table 2.2, sugar plays a role in the temperature at which starch gelatinisation occurs during baking. This step is crucial in cake manufacture as it is the step at which the cake batter sets. If starch gelatinisation does not occur at the correct point, it could result in cracks within the internal crumb structure of the cake and further impact on thermosetting (the step where gas is released from the cake) which can negatively affect the specific volume of the cake. During starch gelatinisation, amylose is leached, which is important during the cooling stage as the amylose undergoes retrogradation which prevents the cake from collapsing and impacts on the softness of the crumb.

Lastly, Van der Sman and Renzetti (2020) discussed the effect of sugar on the final cake product. As mentioned previously, sugar plays a role in amylose retrogradation during the cooling phase which can subsequently impact on staling of the final product. With this, sugar can help to delay staling and ultimately extend the shelf-life of cakes. As also mentioned in the study by Sahin *et al.* (2019), sugar plays a role in the Maillard reaction which helps contribute towards the appearance and flavour of the final product. The authors noted that sugar also adds sweetness to the final product.

Mixing	**Baking**	**Cooling**	**Final Product**
- Air incorporation - Increased viscosity - Affects	- Affects viscosity - Affects temperature at which	- Influences amylose retrogradation	- Delays staling - Extends shelf-life - Taste

protein hydration	starch gelatinisation occurs		- Crust colour

Table 2.2. The effect of sugar during the processing of cakes and the final product (adapted from data within Van der Sman and Renzetti, 2020).

2.3 Sugar replacers in cake manufacture

As sugar plays a technologically important role in the manufacture of cakes, many manufacturers have reported concerns around reducing sugar without resulting in an increase in other nutrients including saturated fat, calories and salt (PHE, 2017).

During reformulation, manufacturers may choose to adjust the recipe in order to reduce the amount of sugar added, or they might seek out ingredients which will replace the various functions that sugar has in cakes (Van der Sman and Renzetti, 2020). However, unfortunately, no single ingredient can replace sugar in a product (Auerbach and Dedman, 2012).

As mentioned in Table 2.1 and Table 2.2, sugar plays a key role in the manufacture of cakes. It is recognised that manufacturers may utilise food additives, such as bulking agents or high-intensity sweeteners, to reduce the sugar content of cake recipes (Sahin *et al*., 2019). Food additives permitted for use in food in the EU, and their conditions, are laid down in Regulation (EC) No. 1333/2008 (2008). In an article which discussed the functionality of bulking agents, the authors noted that it can be challenging for only one singular bulking agent or high-intensity sweetener to replace the functions of sugar, however a combination of the two has been established as a promising strategy (Auerbach & Dedman, 2012).

Bulking agents may be classified as sweet or non-sweet, and can include non-digestible carbohydrates, resistant starches, oligosaccharides, and polyols (Di Monaco *et al.*, 2018). Polydextrose is an example of a non-digestible carbohydrate, inulin is an

example of an oligosaccharide. Aspartame, acesulfame k, sucralose, saccharin, ETC are considered high-intensity sweeteners (Mooradian, Smith and Tokuda, 2017). Polyols may include erythritol, isomalt, lactitol, maltitol, sorbitol and xylitol (Mooradian, Smith, and Tokuda, 2017).

Demand for 'clean-label' ingredients is growing in popularity amongst consumers (Saraiva *et al.*, 2020). There is no legislative or guideline definition of the term 'clean label' however Ingredion (2014) in their report on 'clean labels', they define a 'clean label' as one that is 'natural', 'organic', 'free from additives and preservatives' and contains ingredients which a consumer might find in their kitchen cupboard. In a study which examined the growing 'clean label' trend, the researchers emphasised that food manufacturers should consider the demand for clean labels, as consumers are looking for products that are 'natural' and 'free from' artificial ingredients (Asioli *et al*., 2017).

In a report by PHE (2017), many food businesses have reported that they did not wish to use food additives which would be considered 'artificial' in their cakes products while other food businesses reported that having products which contain these ingredients can enable the consumer to make an informed decision when selecting cake products.

2.4 Consumer perceptions of reduced sugar food products

In a report by Safefood (2019), it was explored if nutrition and health claims impact on consumers' choice. The report found that consumers believe if a product contains nutrition and health claims, that the product will cost more, while other consumers shared concerns that if a product claims to be low in a particular nutrient that it might be high in another target nutrient, for example if a product has a 'low fat' claim, then it might contain more sugar to make up for the reduction in fat. Another finding related to if a product has a nutrition claim, that it might not taste as nice as a product without a claim.

A report into consumer perceptions of reformulated bakery products in Northern Ireland (NI), assessed shopping habits, eating habits and their views on product reformulation

(FSA, 2019). The second stage involved obtaining information on consumer attitudes and behaviours across a two-week period whereby 40 participants were asked to complete tasks on a specially-developed app so the researchers could gather information on claimed and actual behaviours. The third stage involved carrying out an online survey of 305 participants across NI which looked at eating habits, awareness of foods high in salt, sugar and saturated fat, portion sizes, perceptions of foods which have been reduced in a specific nutrient e.g. reduced sugar, and their opinion on manufacturers making their products healthier.

The FSA found that consumers were less likely to report wanting healthier alternatives when it comes to cakes, with 31% of consumers reported that they wanted healthier options of cakes (FSA, 2019). The top factors for consumers not wanting healthier cake alternatives included healthier options not tasting as good (31%), they are not looking for healthier alternatives (27%), the original options are more appealing (25%), and there are not many healthier options available (19%). The FSA (2019) also reported that qualitatively, consumers have a stronger positive emotional response to eating treat foods such as cake, so this may result in a reluctance to wanting to eat healthier options. This research from FSA (2019) highlighted that 75% of consumers reported they would buy cakes which were reduced in sugar. Of the 25% who would not buy cakes which were reduced in sugar, 76% said taste was their reason for not buying.

Mr. Kipling is a brand within the Premier Foods Portfolio which has reported to have successfully reduced the sugar content of their cake products without experiencing any negativity from consumers (FDF, 2020). Mr. Kipling has a wide range of cake products including Bramley Apple Pies, Angel Slices, Lemon Slices and French Fancies. Mr. Kipling has reformulated a number of their cake products to reduce sugar, fat and calorie content. An example of this is their Bramley Apple Pies in which they reduced the sugar content by 9%. Another way that Mr. Kipling is meeting Public Health England's Sugar Reduction and Wider Reformulation Programme targets is through new product development in which they have launched reduced-sugar versions of their best-selling products which are called "Deliciously Good". These products include

Angel Slices, Chocolate Slices and Lemon Slices. In this range, sugar was reduced by 30% through reformulation and by reducing portion sizes. According to Kantar data collected in 2019, in less than a year of launching, Premier Foods has seen these Deliciously Good products entering their top 100 best-selling SKU's of sweet treats products.

2.5 The use of nutrition claims on products

As outlined in Table 2.3, under EU legislation, there are a number of permitted nutrition claims which can be used on food product labelling to help food products stand out from their competitors. Nutrition claims are voluntary however some manufacturers may choose to add them to their packaging. With consumer demand for healthier products, food businesses may wish to use nutrition claims to enable the consumer to make informed decisions.

Nutrition claim	**Condition for use**
Low energy	No more than: ● 40kcal/100g for solids ● 20kcal/100g for liquids.
Energy-reduced	Minimum 30% reduction in energy, with the characteristic which makes the food reduced in energy being indicated.
Energy-free	No more than 4kcal/100ml.
Low sugar	No more than: ● 5g sugar/100g for solids ● 2.5g sugar/100ml for liquids.
Sugar-free	No more than 0.5g sugar per 100g or 100ml.
With no added sugar	No added mono- or disaccharides, or no added food which is used for sweetening purposes and contains

	mono- or disaccharides.
Reduced sugar	A minimum of 30% reduction in sugar compared to a similar product.

Table 2.3. Nutrition claims, and associated conditions, which are permitted under EU legislation (adapted from Regulation (EC) No. 1924/2006, 2006).

2.6 Thesis outline

A review of the literature has demonstrated that sugar plays a key role in the manufacture of cakes, and reducing the sugar content of cakes may be challenging for food manufacturers. In ROI, voluntary reformulation targets have been set for sugar reduction of 20% in cakes by 2025. The literature has shown that consumption of cakes is one of leading contributors of sugar in the Irish diet, particularly in Irish males. While public health reports have highlighted that sugar is one of the leading dietary causes of weight gain, which may lead to the development of NCNs. Sugar replacers such as food additives are a popular way to reduce sugar in cakes, while novel approaches such as the use of sourdough technology is becoming the topic of more studies. Evidence shows that there is a consumer demand for healthier products however there is concern that reformulated products may not taste as good as the original products.

Chapter 3: Methods and Materials

3.1 Methods - Study Design

This section provides a framework for the methods used to establish how sugar can be reduced in cakes. The research methods used included a review of published, peer-reviewed, scientific papers, and a review of publications from both governmental and non-governmental sources. Primary research was conducted through the collection of nutritional information of cakes for sale in the top Irish grocery supermarkets in order to determine prevalence of reformulated cakes on the market and whether low sugar content results in an increase in another nutrient.

3.1.1 Thesis Outline of Research

It is widely recognised that sugar plays a crucial functional role in the manufacture of cakes however, studies have shown there are a number of ways that manufacturers can reduce the sugar content of cakes. Therefore, the research question presented in this thesis is whether it is possible for manufacturers to successfully reduce the sugar content of their cake products, in line with the voluntary target of 20% reduction by 2025. This thesis will also assess any potential opportunities for cake manufacturers the current market by cakes for sale in top Irish retailers in terms of nutritional content and claims.

With regard to addressing the research question, Chapter 1 gave an overview of overweight and obesity from a population perspective, and their impact on the development of NCDs, which led onto an outline of reformulation as a public health strategy to reduce the prevalence of overweight and obesity. Chapter 2 outlined the importance of sugar in the manufacture of cakes and gave an introduction to some of the strategies employed in reducing sugar content, alongside some examples of what some food businesses have done with their cake products in order to meet voluntary sugar reduction targets.

Chapter 3 will summarise the methodologies and study design selected to answer the research question. Results and findings which showcase the potential strategies to reduce the sugar content of cakes will be stated in Chapter 4, while Chapter 5 will

critically discuss these results and review their viability in successful sugar reduction. Chapter 6 will conclude the thesis and give a synopsis of the key findings and recommendations for future work.

3.1.2 Scope

The scope of the research question is focused on the strategies employed in reducing sugar content of cakes in order to meet the voluntary reformulation target set for sugar. The scope will explore the use of food additives, natural sweeteners and sourdough technology as a means of replacing sugar as an ingredient, while the scope will also assess how manufacturers can utilise labelling when reducing sugar. Sugar was selected due to it being identified as a target nutrient in ROI's 'A Roadmap for Reformulation', while cake was selected as it was identified as a priority food category in the Roadmap. The strategies employed in reducing sugar content of cakes, which were explored in this thesis, include assessing sugar replacers in terms of their physical properties, organoleptic properties, The functionality of sugar replacers in terms of their contribution towards specific volume, crust and crumb colour, overall appearance, sweetness, bite, and flavour was explored while the potential for manufacturers to use nutrition claims was also discussed.

3.1.3 Selection of Studies

Studies were considered eligible if they assessed sugar reduction of cakes using food additives, natural sweeteners or sourdough technology. Studies were also considered acceptable if they addressed consumer perceptions of sugar reduction. For studies examining the use of food additives, the following definitions were used; artificial sweeteners, high-intensity sweeteners, polyols, and bulking agents.

3.1.4 Data Inclusions

Secondary data included in this thesis was gathered from peer-reviewed, scientific studies. Data has been attained from articles available in recognised scientific journals, which were typically published within the last five years. Any data used which was published more than five years ago, was deemed acceptable if the information was still

considered relevant and had not been replaced with new data. Cakes were selected for inclusion if they had a similar product description to Table 3.1, which is based on criteria laid down from a similar survey conducted by Hashem *et al*. (2017).

Cake Category	**Product description and example**
Almond	Almond slices or fingers
Angel	Angel cake or slices
Bakewell	Bakewell slices
Battenberg	Battenberg
Blueberry muffins	Blueberry muffins
Brownies	Brownies
Carrot	Carrot cake or similar
Chocolate	Chocolate cake or similar
Chocolate cake bar	Chocolate cake bars, including caramel flavour
Chocolate muffins	Chocolate muffins, including chocolate chip and double chocolate
Chocolate Swiss roll	Chocolate Swiss roll or chocolate roll or sponge roll
Coffee and walnut	Coffee and walnut cake or similar
Coffee	Coffee cake including iced or containing buttercream
Cupcake/fairy cakes	Cupcakes or fairy cakes
Fruit Swiss roll	Swiss roll, and fruit flavoured e.g. Raspberry Swiss roll
Lemon	Lemon cake and slices, or similar

Lemon Swiss roll	Lemon Swiss roll or similar
Madeira	Madeira cake, including iced variety
Red velvet	Red velvet cake and cupcakes
Victoria	Victoria sponge or similar
White chocolate	White chocolate cake
Plain with chocolate	Plain sponge with chocolate chips or topped with chocolate

Table 3.1. Description and examples of cake categories (adapted from data within Hashem *et al*., 2017).

3.1.5 Data Exclusions

Data from studies which were not peer-reviewed were omitted from the study. Unsubstantiated data was also not included in the study.

3.2 Materials

3.2.1 Sample Selection, Categorisation and Collection

Data relating to nutrition content and nutrition claims were collected from cakes sold in Irish supermarkets (n=5), which were available both in-store and online, between March and April 2023. Selection of retailers was assessed based on Irish grocery market share data, as presented in Figure 3.1. The top five supermarkets in the Republic of Ireland were selected as they included multiple and discount retailers which were representative of the products available at varying budgets in the population. Dunnes Stores was identified as having the largest share of the Irish grocery market, with a share of 23.6%. In second place was Tesco with 22.9%, SuperValu was in third place with a share of 20.8%. Lidl and Aldi were in fourth and fifth place, respectively, with shares of 12.6% and 11.7%.

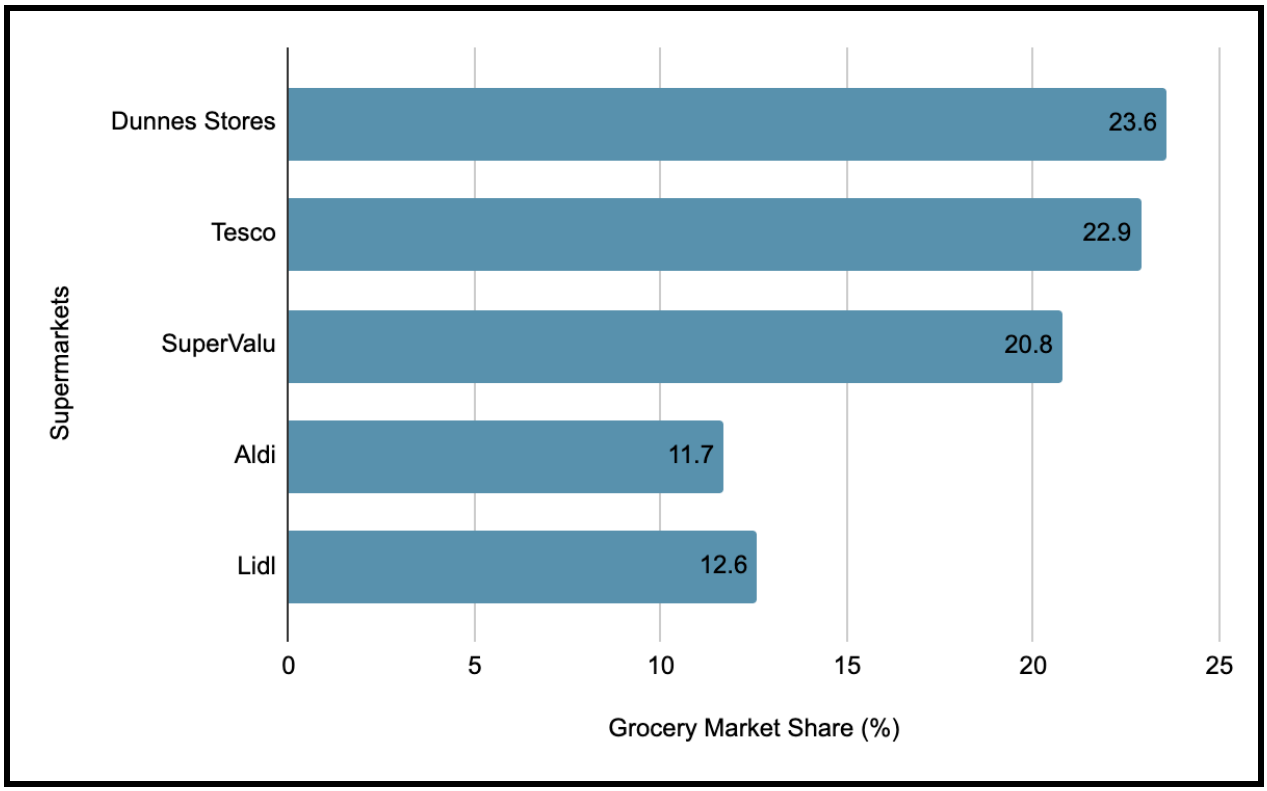


Figure 3.1. Top five supermarkets in the Republic of Ireland, as identified using grocery market share data (adapted from data by Kantar Worldpanel, 2023).

3.2.2 Products Description and Data Collection

This study collected data on 234 cakes from 36 brands which were available for sale in top Irish retailers (Dunnes Stores, Tesco, SuperValu, Lidl and Aldi). In total, 48.07% of the products surveyed were branded products such as Stafford's Bakery, Mr. Kipling or Matt Reilly Cakes) while the remaining products were own-brand products (51.93%) from Dunnes Stores, Tesco, SuperValu, Lidl and Aldi. Data was collected over a 3-week period across March and April 2023.

Tesco, Dunnes Stores, SuperValu and Aldi had nutritional information and information relating to nutrition claims for cakes available for sale on retailer websites. A search for relevant products was conducted in-store and on retailer websites by searching in the 'Bakery', 'Cakes', 'Muffins', 'Free From' and 'Gluten Free' aisles.

Store visits were carried out by visiting the top five supermarkets (Tesco, Dunnes Stores, SuperValu, Lidl and Aldi). The supermarkets selected were located in Dublin, due to convenience. Data collection consisted of taking photographs of the labelling on cake products for sale in supermarkets, which were not available on their online store. Permission to photograph food products as part of data collection was requested from the Store Manager for each supermarket visited.

The following data was collected for each product: brand name, product name, nutrition information per 100g (energy, fat, saturated fat, carbohydrate, sugar, protein, fibre and salt), and any nutrition claims relating to sugar and/or energy. Where multiple pack sizes existed for the same product, the largest pack size was selected for data collection as the larger surface area may allow for inclusion of nutrition claims relating to the product. Products excluded were those which did not meet the criteria set out in Table 3.1.

3.2.3 Product Categorisation

The products were categorised separately into supermarket own-brand and branded products.

3.3 Statistical Analysis

Data relating to nutritional content of cakes was recorded and analysed using descriptive statistics on Microsoft Excel. The count, mean, median, and standard deviation values were calculated for nutrients including energy (calories) fat, saturated fat, carbohydrate, sugar, fibre, protein and salt. macronutrients and salt.

Analysis using Pearson correlation coefficient was used to study whether changes in sugar content correlates to changes in another nutrient (fat, saturated fat, fibre, protein, and salt). For the purpose of this study, r = 1 indicates a very strong relationship, while <0.20 indicates a very weak relationship (BMJ, 2020).

3.4 Study Limitations

Nutrition information per serving while information relating to individual serving sizes were not available for all products on retailer websites. Due to time constraints, this data was not collected during store visits.

Chapter 4: Results

In ROI, the government has set a voluntary reformulation target for sugar in which they aim to see a 20% reduction in sugar across agreed priority food categories by 2025. In total, nine priority food categories have been identified as a focus for sugar reduction, with cakes being one of the nine categories for sugar reduction. It is recognised that reducing the sugar content of cakes can be a challenging task for manufacturers to undertake as sugar plays a key role in the manufacture, sensory attributes and shelf-life of cakes. In this chapter, the role of food additives, 'clean-label' ingredients and sourdough technology in helping replace sugar in cakes will be outlined. This chapter will also give an overview of the nutritional status of cakes for sale in Ireland.

4.1 The effect of food additives as sugar replacers in the processing of cakes

Several studies have investigated the effect of food additives, including polyols and artificial sweeteners, as a means of reducing the sugar content of cakes.

In a review of the strategies available to reduce sugar in baked goods, Sahin *et al*. (2019) discussed the effects of a number of food additives (n=6) as sugar replacers in cakes and muffins which is detailed in Table 4.1. The bulking agents, polydextrose and oligofructose, were both found to aid browning of cakes. Polydextrose was found to lower specific volume yet caused the mean air bubble size in the cake batter to increase. Oligofructose maintained specific volume but increased crumb firmness of sponge cake. Polydextrose and oligofructose possess a sweetness of 20% and 25%-50%, respectively, to that of sucrose. For artificial sweeteners, aspartame and rebaudioside A caused a bitter aftertaste. All of the artificial sweeteners listed in Table 4.1 resulted in a lower specific volume. Acesulfame K and rebaudioside A resulted in less of a browning reaction and a harder crumb. When sucralose and rebaudioside A replaced sugar in muffins, they resulted in a denser crumb.

Food additive category	**Food additive**	**Sweetness relative to sucrose =**	**Product where the additive**	**Additive effect**	**Reference**

		1	**has replaced the sugar**		
Bulking agents	Polydextrose	0.2	High-ratio cake Chiffon cake Pound cake	- Aids browning - Lower specific volume - Increases mean air bubble size in batter - Reduces batter viscosity	Hicsasmaz *et a*l., 2003 Martinez -Cervera *et a*l., (2012)
	Oligofructose	0.25 - 0.5	Sponge cake	- Aids browning - Maintains specific volume - Increases cake crumb firmness	Ronda *et al*., 2005
Artificial sweeteners	Aspartame	200	Sponge cake	- Lower specific volume - Bitter aftertaste	Attia *et al*., 1993
	Acesulfame-K	200	Sponge cake	- Lower specific volume - Less browning reaction - Harder crumb	Attia *et al*., 1993
	Sucralose	600	Muffins	- Denser crumb	Martinez

				structure - Lower specific volume	-Cervera *et al*., (2012)
	Rebaudioside A	250 - 450	Muffins	- Bitter aftertaste - Lower specific volume - Denser crumb structure - Harder crumb - Less browning reaction	Gao *et al*., 2017

Table 4.1. The effects of food additives as sugar replacers in cakes (adapted from data within Sahin *et al*., 2019).

Polyol	**Relative sweetness**	**End-product effect**
Mannitol	50-70	● Increased batter stability ● Increased specific volume ● Less browning reaction ● Increased crumb firmness
Sorbitol	50-70	● Starch gelatinisation occurred at a lower peak temperature ● Lower muffin height ● Softer crumb texture ● Specific volume not affected negatively ● Less browning reaction
Maltitol	75	● Temperature during starch gelatinisation not

		affected ● Lower muffin height ● Softer crumb texture ● Less browning reaction ● Lower specific volume
Erythritol	60-80	● Starch gelatinisation occurred at a lower peak temperature ● Lower muffin height ● Increased muffin hardness ● Increased chewiness ● Lower score for sensory acceptance
Isomalt	45-65	● Temperature during starch gelatinisation not affected ● Lower muffin height ● Softer crumb texture ● Decreased chewiness ● Lower score for sensory acceptance
Xylitol	100	● Less browning reaction ● Specific volume not affected negatively ● Decreased crumb hardness ● Higher score for sensory acceptance ● No loss in sweetness

Table 4.2. Effects of polyols on cakes and muffins when sugar is reduced by 100% (adapted from Sahin *et al*., 2019).

Sahin *et al*. (2019) in their review of the literature, assessed the effects of polyols (n=6) on cake and muffin end-products, when sugar has been reduced by 100% (see Table 4.2). Of all the polyols assessed, xylitol was the closest in sweetness to sucrose. In terms of specific volume, mannitol caused an increase while maltitol caused a

decrease. Sorbitol and xylitol had no negative impact on specific volume. Cakes made with mannitol, sorbitol, maltitol and xylitol had less of a browning reaction than the control cake which was prepared with sucrose. In relation to the crumb, mannitol caused an increased crumb firmness, xylitol caused a decreased crumb hardness while sorbitol, maltitol and isomalt resulted in a softer crumb texture. Muffins made with sorbitol, maltitol, erythritol and isomalt had a lower muffin height than the control. A lower sensory acceptance score was reported for isomalt while a higher sensory acceptance score was reported for xylitol. Starch gelatinisation in cakes and muffins made with sorbitol and erythritol occurred at a lower peak temperature while the temperature at which starch gelatinisation occurred in cakes and muffins made with maltitol and isomalt was not affected. In relation to chewiness, products made with erythritol had an increase in chewiness while those made with isomalt had a decrease in chewiness. The use of mannitol as a replacement caused an increase in batter stability.

Milner *et al*. (2020) examined the use of clean label, novel sweetening ingredients as a means of replacing sugar in cakes. The ingredients used were apple pomace, whey permeate, oligofructose and polydextrose. The researchers selected whey permeate because when dried, it contains a minimum of 85% lactose. Although lactose is not as sweet as sucrose, it does participate in the Maillard reaction and can help with browning and crust formation. Apple pomace is an ingredient which has been used in cakes to increase the fibre content, however it can also increase the perceived sweetness of a product. Oligofructose is a dietary fibre which has been found to be as sweet as sucrose when used in concentrations as high as 35%, and is good at high temperatures whilst acting as a humectant. Polydextrose is a dietary fibre which is not as sweet as sucrose yet plays a role in thickening cake batter, browning, and increasing the temperature at which gelatinisation of starch occurs.

The researchers analysed the cakes in terms of specific volume, crumb and crust colour, moisture, and quality attributes. Figure 4.1 demonstrates the specific volume of the cakes prepared by Milner *et al.* (2020). Based on this, the control cake had the

highest specific volume and this was significantly different to the specific volume of the cake prepared with apple pomace. Of the sugar reduced cakes, the cake prepared with whey permeate experienced the highest specific volume while the cake prepared with apple pomace had the lowest reported specific volume.

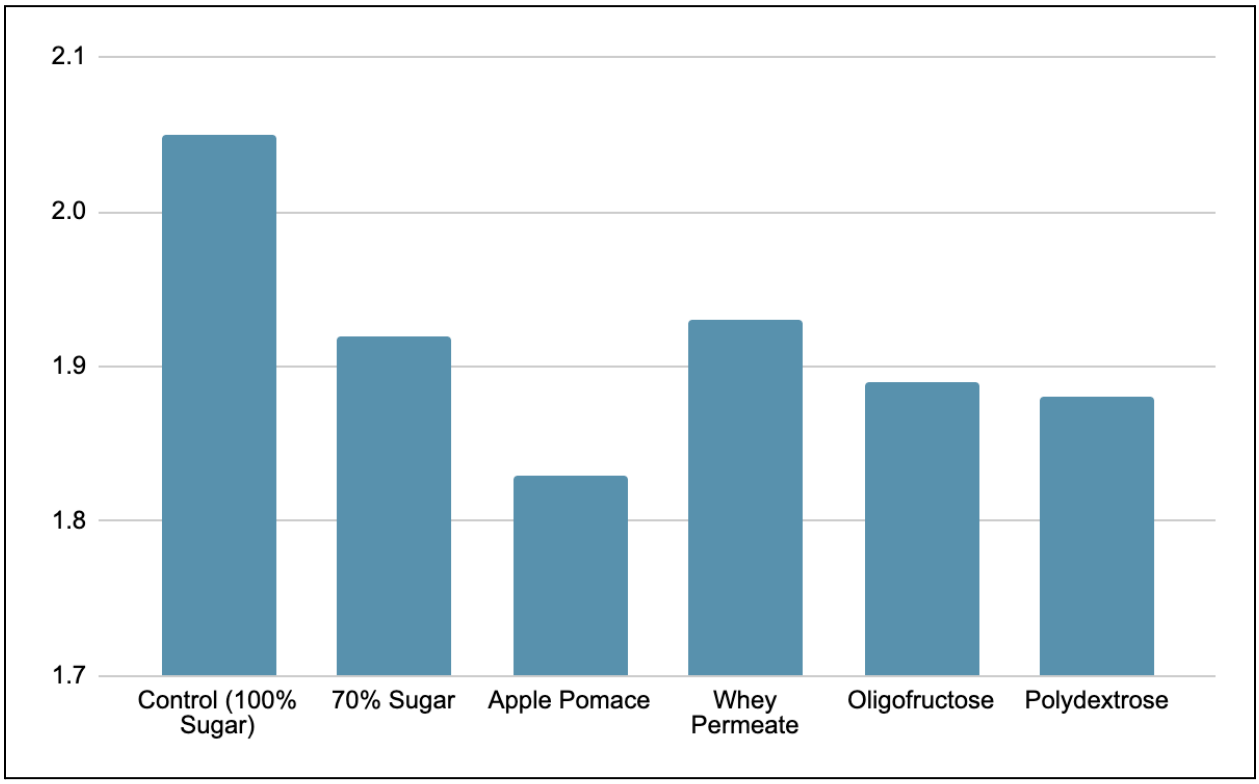


Figure 4.1. Specific volume of control cake (100% sugar) and reduced-sugar cakes prepared with 70% sugar, apple pomace, whey permeate, oligofructose and polydextrose. Different superscript values indicate significant differences ($p<0.05$) between cakes (adapted from data within Milner *et al*., 2020).

4.2 The use of sourdough technology in sugar-reduced cakes

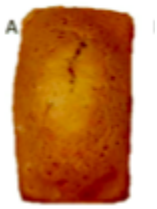
Sahin et al. (2019) conducted a study into the use of sourdough as a means of reducing the sugar content of high-ratio cakes. The authors prepared nine cakes and compared them with a control cake which contained sugar. Based on previous research carried out by the researchers, the type of sourdough (SD) used in this study was sourdough

fermentation which produces the lactic acid bacteria strain Leuconostoc citreum TR116. The composition of the cakes is outlined in full in Table 4.3, however in some cake preparations, fructose (FRU) is added to the sourdough to activate mannitol production. Once the cakes had been baked, the researchers analysed the physical characteristics through visual assessments and the employment of a sensory evaluation panel consisting of 10 trained people.

Cake Type	**Cake Identification**	**Cake Composition**
Non reduced-sugar	C1	30% sucrose
Reduced-sugar	C2	15% sucrose and 15% wheat starch
Reduced-sugar	C3	15% sucrose and 15% commercial mannitol
Reduced-sugar with sourdough (SD)	C2 + 5% SD	15% sucrose, 15% wheat starch, and 5% SD
Reduced-sugar with sourdough (SD)	C2 + 10% SD	15% sucrose, 15% wheat starch, and 10% SD
Reduced-sugar with sourdough (SD)	C2 + 20% SD	15% sucrose, 15% wheat starch, and 20% SD
Reduced-sugar with sourdough (SD_{FRU})	C2 + 5% SD_{FRU}	15% sucrose, 15% wheat starch, and 5% SD_{FRU}
Reduced-sugar with sourdough (SD_{FRU})	C2 + 10% SD_{FRU}	15% sucrose, 15% wheat starch, and 10% SD_{FRU}
Reduced-sugar with sourdough (SD_{FRU})	C2 + 20% SD_{FRU}	15% sucrose, 15% wheat starch, and 20% SD_{FRU}

Table 4.3. Composition of non reduced-sugar and reduced sugar cakes, including those prepared using sourdough (adapted from Sahin *et al.,* 2019)

In the visual assessment of the cakes, the researchers took images of the exterior (crust) and interior (crumb) of each cake to compare the appearance of each cake (see Table 4.4). When inspecting the crust, the researchers concluded that the control cake (C1) had experienced more browning than the other cakes, while C2 had the least amount of browning and was notably pale in colour. When fructose was added at 5% and 10% to the sourdough, the crust was more brown in colour and most similar in appearance to the control cake.

Cake Identification	**Crust**	**Crumb**
C1		
C2		
C3		

C2 + 5% SD		
C2 + 10% SD		
C2 + 20% SD		
C2 + 5% SD$_{FRU}$		
C2 + 10% SD$_{FRU}$		
C2 + 20% SD$_{FRU}$		

Table 4.4. Appearance of the crust and crumb of the high-ratio cakes (images taken from Sahin *et al.*, 2019).

4.3 The effect of sugar replacers on sensory attributes of cakes

Clemens *et al.* (2016) gathered data from the USDA database on the sugar and dietary fibre content of sugars, natural sweeteners, corn syrups and HFCS (n=18), as listed in Table 4.5. Granulated Sugar had the highest total sugars content (99.8g/100g) while Guava Nectar had the lowest total sugars content (12.4g/100g). There was no date for total sugars content of Agave Syrup. Granulated Sugar had the highest sucrose content (99.8g/100g) while Grape Juice and Agave Syrup contained the least amount of sucrose (0g/100g). No data was available for the sucrose content of six products. Honey had the highest glucose content (35.8g/100g) while Turbinado Sugar and Granulated Sugar had the lowest glucose content (0g/100g). No data was available on the glucose content of six products. Agave Syrup had the highest fructose content (55.6g/100g) while Canadian Maple Syrup had the lowest fructose content (0.3g/100g) There was no data available on the fructose content of eight products. In relation to total dietary fibre, Medjool Dates had the highest fibre content (6.7g/100g) while there were 11 products in total that contained 0g/100g of dietary fibre (Molasses, Brown Sugar, Granulated Sugar, Maple Syrup, Powdered Sugar, Canadian Maple Syrup, Dark Corn Syrup, HFCS, Light Corn Syrup, Malt Syrup, and Sorghum Syrup).

Product	**Total Sugars *(g/100g)***	**Sucrose *(g/100g)***	**Glucose *(g/100g)***	**Fructose *(g/100g)***	**Total Dietary Fibre *(g/100g)***
Dates, deglet noor	63.4	23.8	19.9	19.6	8
Dates, medjool	66.5	0.5	33.7	32	6.7
Grape juice	14.2	0	6.8	7.4	0.2
Guava nectar	12.4	0.2	5.9	5.6	1

Honey	82.1	0.9	35.8	40.9	0.2
Molasses	74.7	29.4	11.9	12.8	0
Sugar, turbinado	99.2	99.2	0	-	-
Sugar, brown	97	94.6	1.4	1.1	0
Sugar, granulated	99.8	99.8	0	-	0
Syrup, maple	84.9	58.3	1.6	0.5	0
Sugar, powdered	97.8	-	-	-	0
Syrup, agave	-	0	12.4	55.6	0.2
Syrup, maple, Canadian	59.9	58.9	0.7	0.3	0
Syrup, corn, dark	77.6	-	-	-	0
Syrup, corn, high-fructose	75.7	-	-	-	0
Syrup, corn, light	76.8	-	-	-	0
Syrup, malt	71.3	-	-	-	0
Syrup, sorghum	74.9	-	-	-	0

Table 4.5. The sugar and dietary fibre content of sugars, natural sweeteners, corn syrups and high-fructose corn syrups (adapted from data within Clemens *et al.*, 2016).

Table 4.6 showcases the results from a sensory evaluation carried out on rice chiffon cakes which were prepared with sugar and polyols (sorbitol, maltitol, xylitol and mannitol) (Kim, Park and Shin, 2014). The appearance, texture and flavour were

scored on a hedonic scale by a panel of 100 randomly recruited individuals. For crust colour, the cake prepared with mannitol had a significantly different score to the other cakes (p=<0.05), where it scored 3.7. The cake made with maltitol score highest for crust colour (5.8). From crumb colour, cakes made with xylitol was scored highest in darkness (6.4) while cakes made with mannitol scored lowest (4.0). For volume, cakes prepared with xylitol scored highest (5.9) while cakes made with sorbitol scored lowest (4.1). For flavour, cakes prepared with maltitol scored highest (5.5) while mannitol containing cakes scored lowest (4.2). For sweetness, cakes made with xylitol scored highest (5.2) while cakes prepared with mannitol scored lowest (3.2). For moistness, the cakes prepared with sugar and sorbitol scored highest (6.4), while mannitol containing cakes scored lowest (2.9) and were significantly different (p=<0.05) to the other cakes. Lastly, the panel evaluated overall acceptance of the cakes and the cakes made with maltitol and xylitol scored highest (5.6) while the cake made with mannitol scored lowest (3.1).

Sample	Crust colour	Crumb colour	Loaf volume	Flavour	Sweetness	Moistness	Overall acceptance
Control	5.3^{a}	4.6^{bc}	5.6^{a}	5.3^{a}	5.1^{a}	6.4^{a}	5.5^{a}
Sorbitol	5.5^{a}	4.9^{b}	4.1^{c}	5.3^{a}	4.1^{b}	6.4^{a}	4.7^{b}
Maltitol	5.8^{a}	5.8^{a}	5.5^{a}	5.5^{a}	4.3^{b}	6.1^{a}	5.6^{a}
Xylitol	5.5^{a}	6.4^{a}	5.9^{a}	5.0^{a}	5.2^{a}	6.2^{a}	5.6^{a}
Mannitol	3.7^{b}	4.0^{c}	4.7^{b}	4.2^{b}	3.2^{c}	2.9^{b}	3.1^{c}

Table 4.6. Sensory analysis of rice chiffon cakes prepared with different polyols (adapted from data within Kim, Park and Shin, 2014). Values within a column with different subscripts are significantly different (p=<0.05).

Milner *et al.* (2020) conducted sensory analysis as part of their study into the use of clean-label ingredients as sugar replacers in cakes. The results from the sensory

analysis are illustrated in Figure 4.2. Overall, polydextrose, oligofructose, whey permeate and 70% sucrose cakes scored highly for crumb colour and overall appearance. Apple pomace scored lower than the control for all sensory attributes except sweetness.

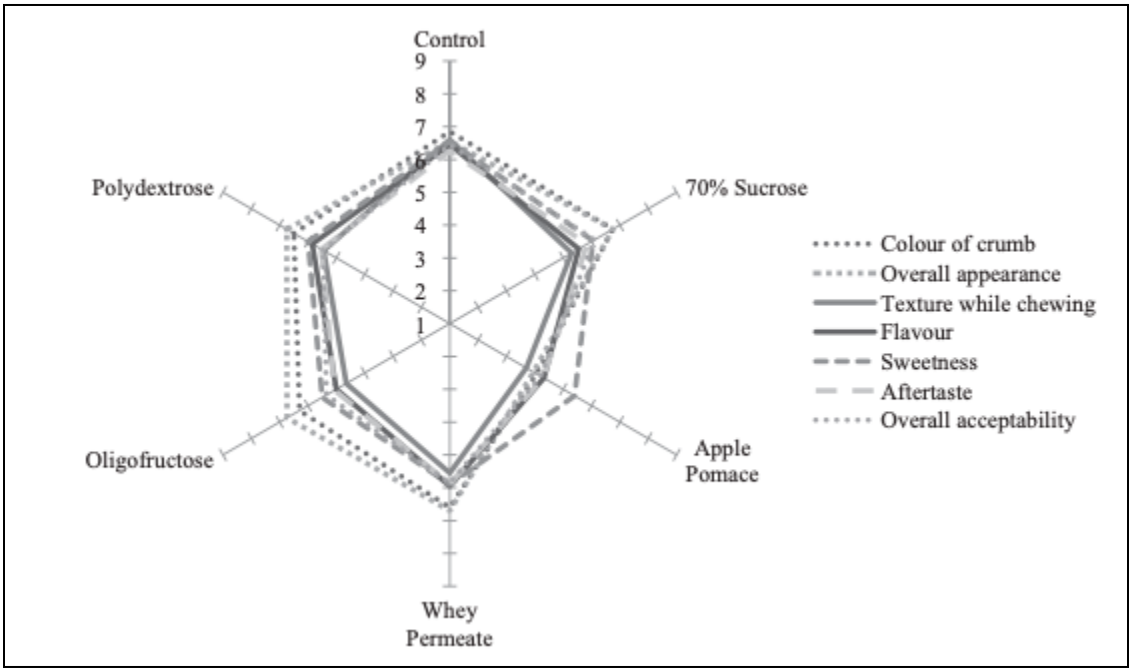


Figure 4.2. Results from sensory analysis of control cake (100% sugar) and reduced-sugar cakes prepared with 70% sugar, apple pomace, whey permeate, oligofructose and polydextrose scored from 1-9 on a hedonic scale (1=extremely dislike, 9=extremely like) (adapted from data within Milner *et al.*, 2020).

In the sensory evaluation of cakes prepared with sourdough, the cakes were rated from 0 to 10 for perceived intensity of a particular attribute, with 0 equaling not perceived at all while 10 would equate to the highest intensity (Sahin *et al.*, 2019). The results of the sensory evaluation are captured in Table 4.7.

Cake ID	**Sweetness**	**Sourness**	**Aroma**	**Flavour**	**Crumb Hardness (Bite)**

C1	8.2	0.1	5.8	6.4	1.4
C2	3.0	0.1	4.0	4.1	6.7
C3	5.6	0.4	4.2	4.7	3.4
C2 + 5% SD	3.6	0.5	4.7	5.2	3.1
C2 + 10% SD	3.8	1.2	4.9	5.7	3.3
C2 + 20% SD	4.1	1.7	5.2	5.9	4.8
C2 + 5% SD_{FRU}	5.3	0.7	5.6	5.9	4.4
C2 + 10% SD_{FRU}	5.8	1.0	5.8	6.5	4.4
C2 + 20% SD_{FRU}	5.8	1.5	5.7	6.5	5.5

Table 4.7. Results of the sensory evaluation of the high-ratio cakes. Values given are averages from hedonic scale scores (1-10) (adapted from data within Sahin *et al.,* 2019).

The panel assessed the cakes for sweetness, sourness, aroma, flavour and crumb hardness (bite). For sweetness, the control (C1) ranked highest (8.2) with the 10% and 20% added fructose cakes coming in joint second (5.8). The C2 cake had the lowest score for sweetness (3.0). For sourness, the 20% sourdough cake ranked the highest (1.7) while C1 and C2 scored the lowest (0.1). For aroma, the control cake (C1) and the 10% added fructose cake scored joint highest (5.8) while C2 had the lowest score (4.0). For flavour, the 10% and 20% added fructose cakes scored highest (6.5) while C2 scored lowest (4.1). For crumb hardness, C1 scored the lowest (1.4) while C2 scored the highest (6.7).

4.4 The effect of sugar replacers on nutritional content of cakes

Milner *et al.* (2020) analysed the sugar content of sugar-reduced cakes against a control cake, which contained sugar. In the study, the researchers examined the functionality of

clean-label sweeteners, including apple pomace, whey permeate, oligofructose, and polydextrose, to replace sugar in cakes. In the study design, sugar was reduced by 30% and replaced by 5% of a clean-label sweetener, based on the weight of flour in the recipe. The researchers measured the sugar content (total sugars, monosaccharides, and disaccharides) of each cake and the results are summarised in Figure 4.3. It was found that when compared with the control, the biggest total sugars reduction was found in the cake prepared with oligofructose (27.6% reduction), while the lowest total sugars reduction was found in the cake containing whey permeate (21.5% reduction). For fructose, the cake prepared with apple pomace contained the highest amount of fructose (0.60g per 100g).

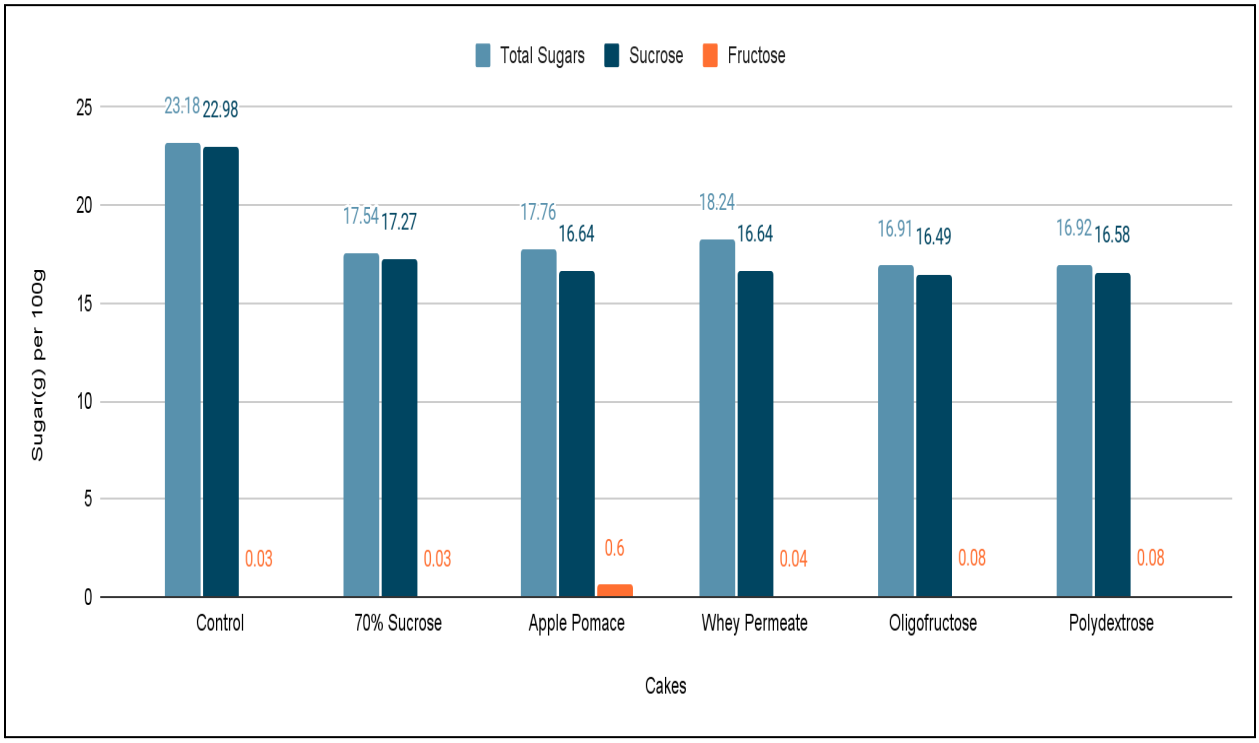


Figure 4.3. Sugar content (g per 100g) of sugar-reduced cakes compared with control cake (adapted from data within Milner *et al.,* 2020).

4.5 The nutritional status of cakes on the Irish market

The data gathered in Table 4.8 displays the descriptive statistics carried out on the nutritional content of cakes that are currently for sale in the top five Irish retailers.

Based on the nutritional content recorded for 234 cake products, the median value for sugar for cakes was 36.8g per 100g, while the mean sugar content for cakes was 35.89g per 100g.

Variable	Count	Mean	Median	SD	Minimum	Maximum
Calories	234	415.96	412.00	48.21	299.00	565.00
Fat	234	19.67	20.00	6.03	1.40	38.37
Saturated Fat	234	7.09	5.78	4.49	0.38	23.00
Carbohydrate	234	54.38	54.35	8.78	6.40	72.90
Sugar	234	35.89	36.80	9.19	11.00	61.30
Fibre	234	1.51	1.30	0.93	0.07	7.80
Protein	234	4.25	4.30	1.42	0	14.19
Salt	234	0.51	0.45	0.24	0.01	1.30

Table 4.8. Descriptive statistics of the nutritional content (g per 100g) of cakes for sale in Irish retailers (n=5).

Figure 4.4 displays the relationship between sugar and fat in cake products (n=234) for sale in Irish retailers. The Pearson correlation coefficient indicates there is a very weak, positive correlation between sugar and fat, saturated fat, fibre, protein, and salt (r^2<0.2), as per Figure 4.4, Figure 4.5, Figure 4.6, Figure 4.7 and Figure 4.8.

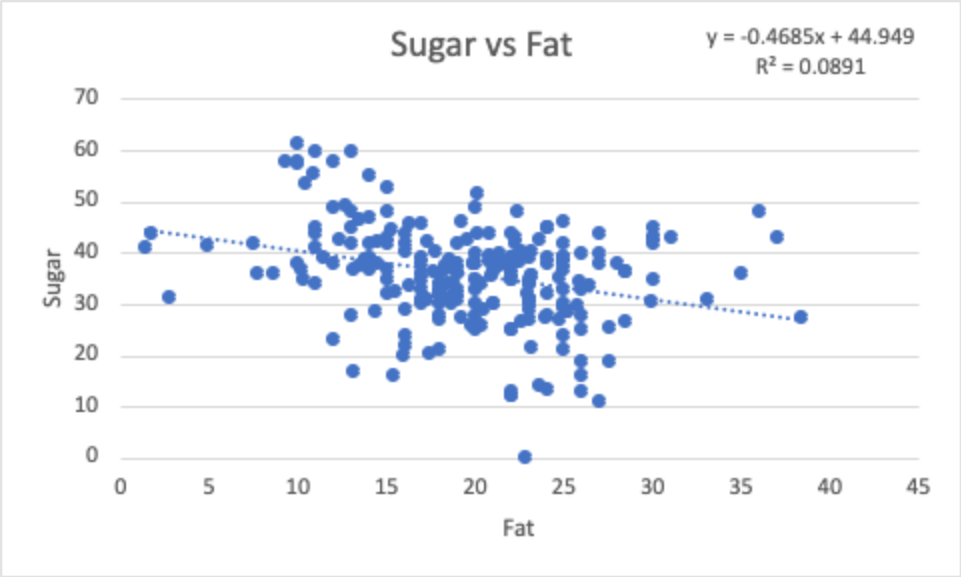


Figure 4.4. Figure showing the relationship between sugar and fat content of cake products (n=234) for sale in Irish retailers (n=5).

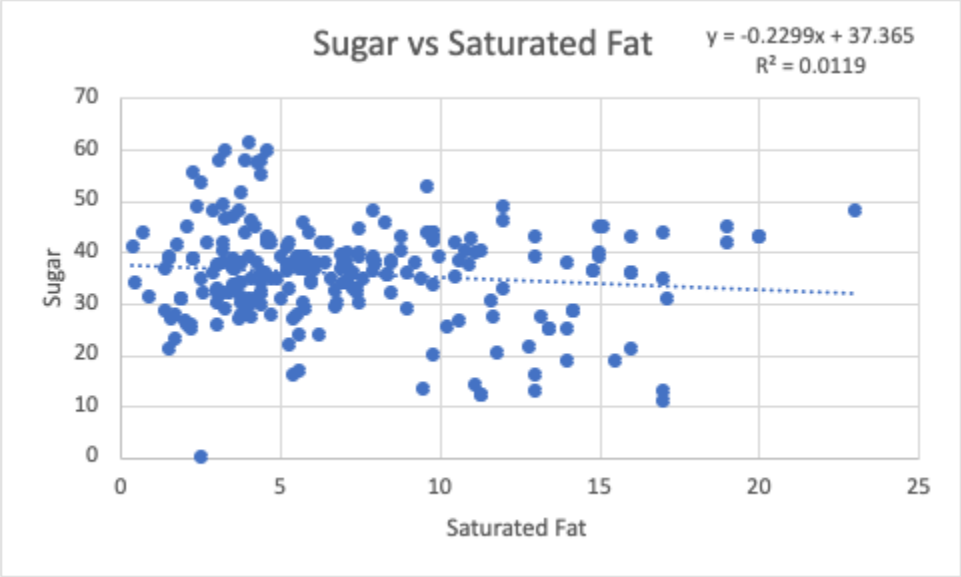


Figure 4.5. Figure showing the relationship between sugar and saturated fat content of cake products (n=234) for sale in Irish retailers (n=5).

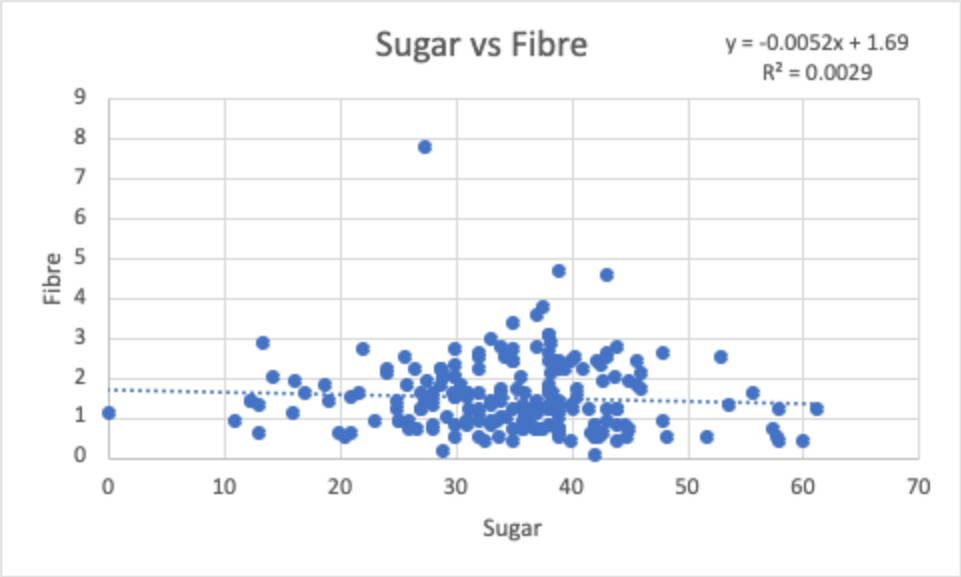


Figure 4.6. Figure showing the relationship between sugar and fibre content of cake products (n=234) for sale in Irish retailers (n=5).

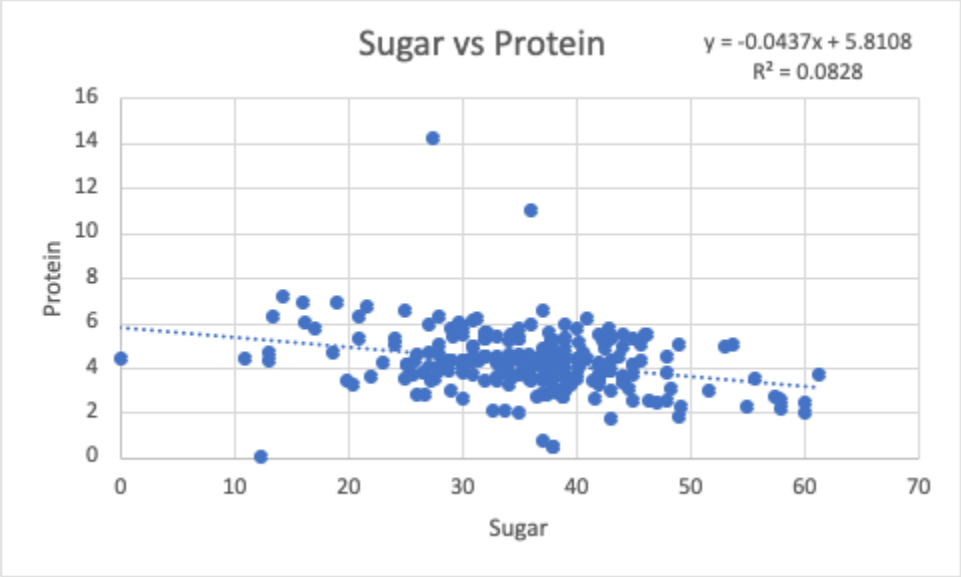


Figure 4.7. Figure showing the relationship between sugar and protein content of cake products (n=234) for sale in Irish retailers (n=5).

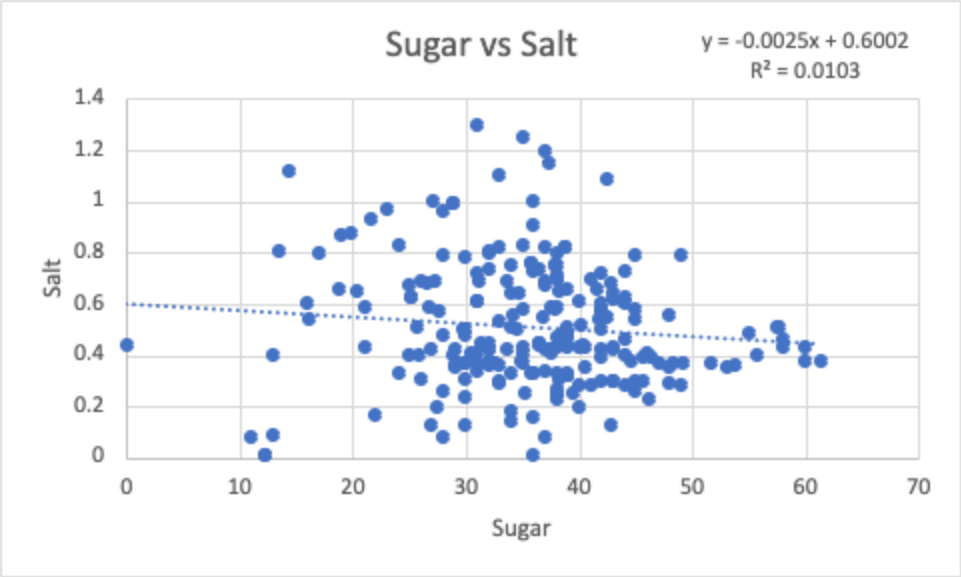


Figure 4.8. Figure showing the relationship between sugar and salt content of cake products (n=234) for sale in Irish retailers (n=5).

A cross-sectional survey of the sugar content of cakes (n=381) for sale in UK supermarkets (n=9) was conducted by Hashem *et al.* (2017), with the results summarised in Table 4.9. The findings suggest that the average sugar content of cakes was 36.6±7.6g per 100g. The authors found that branded cakes contained more sugar than supermarket own-brand cakes (37.7g per 100g vs 36.3g per 100g), however this was not deemed to be significantly different (p=0.137).

Category	**n**	**Sugar content (mean ± SD) (g per 100g)**
Branded	290	36.3 ± 7.4
Own-brand	91	37.7 ± 8.4
All products	381	36.6 ± 7.6

Table 4.9. Sugar content (g per 100g) of cakes for sale in the UK (adapted from data within Hashem *et al.*, 2017).

4.5.1 Nutrition claims on cakes in Ireland

As part of this study, data was collected on nutrition claims relating to energy and sugar which were present on the labels of cakes for sale in top Irish supermarkets. This study found that there were no nutrition claims relating to energy and sugar present on the labels of 234 cakes which were included as part of this study.

4.6 Case studies of reformulation efforts in the UK

The Sugar Reduction and Wider Reformulation Programme in the UK was launched in 2016, and since then, the Programme progress reports which were published throughout the Programme contained updates from food businesses who voluntarily submitted details on their reformulation efforts, with the results summarised in Table 4.10 and Table 4.11 (PHE, 2018; PHE, 2022).

Food Business	**Timeframe**	**Progress**
Asda Stores Ltd	Baseline to Year 1	Reformulated five in-store bakery doughnuts to reduce sugar in the base dough by up to 50%. It was noted this was achieved without any technical issues or changes to processing.
Benugo	Post-Year 1	Across eight products, portion sizes were reduced and recipes were reformulated to achieve an overall reduction in the sugar content.
Bidfood	Post-Year 1	Five tray bakes reformulated; Victoria Sponge, Carrot, Lemon Drizzle, Coffee & Walnut, and Chocolate Fudge. An example would be the Lemon Drizzle in which sugar was reduced from 35.5g to

		24g per 100g. In addition, seven Everyday Favourites baking products were also reformulated.
Compass (Chartlwells)	Post-Year 1	Desserts that were higher in sugar were either reformulated, removed from the menu or reduced in portion size. An example would be Almond and Orange Cake whereby the portion size was reduced from 171g to 80g resulting in a 40% sugar reduction.
Compass (ESS)	Post-Year 1	Reformulation of scratch cook recipes which has resulted in 16.8% reduction in sugar content of cakes.
Costa Coffee	Baseline to Year 1	Sugar per serving was reduced in Raspberry Almond Fingers, the Blueberry Muffin, and the Chocolate Tiffin by 6.9%, 9.1% and 7.8% respectively.
Morrisons Ltd	Post-Year 1	Reformulation of 11 bought-in cakes which was planned to result in 59.3 tonnes less sugar per year. Sugar was reduced in The Best Chocolate Cake by 16.4%.
Premier Foods	Baseline to Year 1	Mr. Kipling Viennese Whirls were reformulated whereby the sugar content of the cream and biscuit parts of the products was reduced. Sugar was reduced from 28.1g to 26.4g per 100g.

Pret a Manger	Post-Year 1	Muffin portion sizes were reduced from 145g to 115g per serving. The company also planned to delist their High Fibre Muffin and reformulate with a lower sugar recipe.
Samworth Brothers	Baseline to Year 1	Soreen, a malt loaf manufacturer, reformulated their recipes and launched single serve products which resulted in a decrease of 4753 tonnes of sugar sold in 2017 compared to 2015.
Starbucks	Pre-Baseline	In 2015, the sugar content of their chocolate brownie was reduced by 30.7% through reformulation of the original recipe.
	Baseline to Year 1	In 2017, their Carrot Cake recipe had a 16% reduction in sugar through removal of the icing on the sides of the cake.
	Post-Year 1	In 2017, Starbucks launched the following five reformulated cakes; ● Lemon Loaf Cake (5.9% sugar reduction). ● Chocolate Marble Loaf Cake (6.8% sugar reduction). ● Pumpkin Loaf Cake (17.2% sugar reduction). ● Ginger Loaf Cake (23.8% sugar reduction). ● Cookies & Cream Cake (27.7%

		sugar reduction).

Table 4.10. Case studies of reformulation efforts from food businesses in the UK (adapted from data by PHE, 2018).

Table 4.10 details individual food business case studies gathered by PHE as part of a progress report on the UK's Sugar Reduction and Wider Reformulation Programme (May, 2018). In total, 11 food businesses provided case study details on their efforts to reformulate their cake products. Asda Stores Ltd. achieved the highest sugar reduction of the 11 food businesses as they noted that they were able to achieve a 50% reduction in the sugar content of their in-store doughnut base dough without any technical challenges or adjustments to their production process. Of the 11 food businesses, Benugo, Compass (Chartlwells), and Pret a Manger (n = 3) highlighted that they reduced the portion size of their products in order to reduce the overall sugar content.

Food Business	**Progress**
Baker & Baker	A new range of muffins were launched which had 21% less sugar than their previous range of muffins. This was achieved through reformulation and portion size reduction.
Bidfood	The Carrot, Coffee & Walnut and the Victoria Sponge recipes of their Everyday Favourites range had their sugar content reduced by 31.7%. This was achieved through reformulation and portion size reduction.
General Mills	Fibre One reduced the sugar content of four of their brownie products, including the Chocolate Fudge Brownie which had a sugar reduction of 33%. Because of this reformulation, it resulted in a subsequent reduction in the calorie content of the product along with an increase in the fibre content.

Lidl	Reformulated six cakes, with sugar reductions ranging from 0.3% to 20% across the products. The pack sizes were also reduced.
Pladis	McVities reduced the sugar content of their Blackcurrant Jaffa Cake Bars by 10.2%.

Table 4.11. Case studies of reformulation efforts from food businesses in the UK (adapted from data by PHE, 2022).

Table 4.11 lists the case studies submitted by individual food businesses to PHE as part of the final industry progress report on the UK's Sugar Reduction Programme (December, 2022). In total, five food businesses provided an update on reformulation efforts of their cake products. Baker & Baker, Bidfood and Lidl (n = 3) highlighted that they reduced the portion sizes of their products in order to achieve a sugar reduction. General Mills achieved the highest sugar reduction whereby the Chocolate Fudge Brownie produced under the brand name Fibre One achieved a 33% sugar reduction.

Chapter 5: Discussion

The purpose and objective of this study was to assess the efficacy of sugar replacers in cakes and to examine the role of labelling in reformulated products. It is recognised that sugar is a crucial ingredient in the manufacture of cakes, due to its role in moisture retention, specific volume and its contribution towards the overall sweetness, however it is recognised that food businesses are reluctant to reformulate their cake products due to the challenges associated with reducing sugar content (PHE, 2017). In a bid to tackle increasing rates of overweight and obesity in ROI, food reformulation has been identified as one of the key areas for addressing the prevalence of overweight and obesity as part of the wider Obesity Policy and Action Plan in Ireland (DoH, 2016). This study aimed to establish how manufacturers can reduce the sugar content of their cake products, in response to the voluntary reformulation sugar target set by the DoH, by understanding the current options available to manufacturers when reducing the sugar content of cakes.

The introductory chapter of this paper provided an overview of the prevalence of overweight and obesity in ROI and the EU which led onto an outline of the food reformulation framework in Ireland which was developing in order to address the incidence of overweight and obesity across the population. The second chapter described the functionality of sugar in the manufacture of cakes while discussing how sugar replacers can be used to reduce sugar content. This second chapter also discussed consumers, including consumption statistics relating to cakes as well consumer perceptions of reformulated products.

The prevalence of overweight and obesity is increasing in adults and children, globally (WHO, 2022a). In ROI, Healthy Ireland (2019) estimates that 61% of adults are overweight or obese, while the incidence of childhood overweight and obesity is typically higher in girls than boys, and higher in children from lower socio-economic backgrounds (Keane, 2014). Historically, obesity is categorised by a body mass index (BMI) of higher than 30kg/m^2, while overweight is identified by a BMI of higher than 25kg/m^2 (Safefood, 2023).

The brain plays a large role in appetite regulation as it relies on hormonal signals from the gut, adipose tissue and several internal organs to balance dietary intake with energy expenditure (Breen *et al.,* 2022). However, obesity can alter these hormonal signals which can lead to an energy imbalance whereby more food is ingested than energy is expended thus leading to even further weight gain (Breen *et al.,* 2022). Environmental factors may also impact on the prevalence of overweight and obesity, with some of these factors including availability of inexpensive and energy-dense foods (Breen *et al*., 2022).

Overweight and obesity is long-associated with the development of NCDs which can be detrimental to human health, while also being costly to government healthcare systems (Safefood, 2017). The WHO aims to halt the increasing global rate of diabetes and obesity by 2025 (WHO, 2013). In a study by Pineda *et al.* (2018), the researchers examined whether the WHO is on track to achieve this aim. Pineda *et al.* (2018) assessed obesity rates in the WHO European region and projected increases in obesity in over 44 countries, with Ireland projected to have the highest prevalence rate (43%). In a bid to tackle the increasing prevalence of overweight and obesity across the population, the Irish government launched the Obesity Policy and Action Plan which sets out the various sectors which contribute to weight gain across the population.

The food industry was identified as a key sector which can play a leadership role in reducing weight gain across the population. Food reformulation is one way that the food industry can contribute towards the health status of the population. Many countries have implemented reformulation frameworks in a bid to encourage the food industry to play their part in reducing the prevalence of overweight and obesity (Kleis, Schulte and Buyken, 2020). In 2021, Ireland launched ‘A Roadmap for Food Product Reformulation in Ireland’ which set out the plan for reformulation of key food categories (DoH, 2021). As part of this roadmap, sugar was identified as a target nutrient for reformulation, and further to this, cakes were identified as one of the main sources of sugar in the Irish diet (DoH, 2021). The DoH aims to see a 20% reduction in the sugar content of cakes by 2025. Food manufacturers in the UK have previously shared concerns for how

reformulation can be carried out without resulting in an increase of another target nutrient (PHE, 2017). Food manufacturers have also highlighted a reluctance to reduce the sugar content as they may have to use artificial sweeteners as sugar replacers, which have negative consumer associations (PHE, 2017). With this, this thesis aimed to critically evaluate the options available to food businesses when reducing sugar in their cake products.

Food additives are promising sugar replacers in cakes (Sahin *et al.*, 2019). Several studies have investigated the use of food additives such as bulking agents (sweet and non-sweet) and high-intensity sweeteners as ways to reduce the sugar content of cakes. Van der Sman and Renzetti (2020), in their review of the functionality of sugar in cakes, mentioned that due to the fact sugar plays a crucial role in achieving a desirable cake texture, that reducing or replacing sugar can be a difficult task for manufacturers. Van der Sman and Renzetti (2020) determined, however, that sweetness and browning could be achieved through the addition of bulking agents and high-intensity sweeteners, while the researchers hypothesised that texture could be maintained through the use of polyols and hydrolysates of dietary fibres.

A widely used method to reduce the sugar content of food is to use a combination of bulking agents and high-intensity sweeteners (Di Monaco *et al.*, 2018). High-intensity sweeteners can help replace the sweetness lost when sugar is reduced or removed from food, however they can not replace the other functions that sugar is responsible for, like texture and appearance (Sahin *et al*., 2019). Bulking agents contribute towards the overall volume and texture of a cake however when used on their own, they tend to decrease the overall sweetness (Sahin *et al*., 2019).

In a paper by Sahin *et al.* (2019), the authors carried out a literature review of the effects of food additives in sugar-reduced bakery products. The authors condensed their research to bulking agents (polydextrose and oligofructose) and artificial sweeteners (aspartame, acesulfame-k, sucralose and rebaudioside A). Overall, the researchers found that polydextrose and oligofructose can contribute towards the

overall browning of a product, which is beneficial for adding to overall appearance and flavour of a product. However, both ingredients were found to have deficiencies when they were assessed in terms of their contribution to physical properties in cakes, such as specific volume, sweetness and softness. Findings from Milner *et al.* (2020) supported this notion whereby cakes prepared with polydextrose did not achieve the same specific volume as that of the control cake which was prepared with sugar. WIth this, Milner *et al.* (2020) concluded that overall, polydextrose is a promising sugar replacer in cakes due to its contribution to browning.

Oligofructose maintained specific volume in cakes but did not possess the same level of sweetness as sugar. Sahin *et al.* (2019) reported aspartame, acesulfame-k, sucralose and rebaudioside A, all possess a high-level of sweetness however, when added to sugar-reduced cakes, they resulted in a lower specific volume in the final product. This supports previous study findings which suggested the use of a combination of a bulking agent and a high-intensity sweetener for replacing sugar in cakes (van der Sman and Renzetti, 2020).

Several studies have investigated the use of polyols to reduce the sugar content of cakes (Kim, Park and Shin, 2014; Sahin *et al.,* 2019). Xylitol is a sweet bulking agent and has found to be a promising sugar replacer in cakes, as it was found to not negatively impact specific volume, and it led to a decrease in crumb hardness which means that the cake expanded similarly to the control cake and was softer in texture (Kim, Park and Shin, 2014). It also scored higher for acceptance during sensory evaluation (Kim, Park and Shin, 2014; Sahin *et al.* 2019). Xylitol is a very sweet ingredient and can fully replace the sweetness lost when sugar is reduced (Sahin *et al*., 2019). However, both Sahin *et al.* (2019) and Kim, Park & Shin (2014) reported that xylitol did not contribute towards the browning of cakes which could negatively impact on the overall appearance of the cakes.

Artificial sweeteners have been gaining popularity in the food industry for the last four decades due to a consumer trend towards zero-calorie products, in a bid to prevent

weight gain (Mooradian, Smith, and Tokuda, 2017). In this study, the role of artificial sweeteners as a means of replacing sugar in cakes has been evaluated. However, it should be noted that although artificial sweeteners may prove promising from a functional perspective, food manufacturers should consider how the consumer will perceive products containing these ingredients. A number of large cohort studies which found a positive correlation of artificial sweeteners with weight gain and type-2 diabetes (Fowler *et al*., 2008; de Koning *et al.*, 2011). Fowler *et al.* (2008) discussed findings from the San Antonio Heart Study in which 3682 adults were monitored over the course of a seven- to eight-year timeframe. The study found that those who consumed at least 21 beverages, containing artificial sweeteners, per week, were more likely to become overweight or obese. In the Health Professionals Follow-Up Study, the authors found a positive correlation between consumption of beverages containing artificial sweeteners and type 2 diabetes, however this was largely influenced by factors such as pre-study weight gain, existing health status, and BMI. In a narrative review of the role of artificial sweeteners in reducing consumption of table sugar, the authors highlighted that based on the evidence, it is possible for artificial sweeteners to induce sweet food cravings due to their sweetness yet low-energy content which may not fully activate the food reward pathway (Mooradian, Smith, and Tokuda, 2017). Despite these findings, little research has been carried out on the effect of artificial sweeteners on health status when they are ingested through the consumption of cakes. As cakes are typically considered by consumers as a 'treat', it is unlikely that the presence of artificial sweeteners in these types of products will negatively impact a consumers' health when they are consumed infrequently and in such small quantities. The San Antonio Heart Study found an association between weight gain and artificial sweeteners when a person consumed at least 21 artificially-sweetened beverages per week. This finding can not be compared to cakes which would be consumed on a more irregular basis.

Under EU legislation, polyols are permitted for use in cakes, however as per Regulation (EC) No. 1333/2008 (2008), they are only permissible in cakes that are 'energy-reduced' (energy value that is reduced by a minimum of 30% compared with

original product or similar) or ‘with no added sugar’ (no added mono- or disaccharides, or no added food which is used for sweetening purposes and contains mono- or disaccharides).

There are some legal considerations to the use of food additives as a means of reducing the sugar content of cakes. Under EU legislation, food additives such as mannitol (E 421), sorbitol (E 420), maltitol (E 965), erythritol (E 968), isomalt (E 953), and xylitol (E 967) are considered Group IV, Polyols. With this, when used as an ingredient in a food product, they are subject to labelling restrictions whereby they must be declared on the ingredients list of a food product with their name and respective E number (Regulation (EC) No. 1333/2008, 2008). Despite there being restrictions on the safe upper limits of use for these types of ingredients, consumers remain wary of consuming E numbers due to the proposed, adverse health risks.

Where polyols, aspartame or aspartame-acesulfame salt are used as an ingredient in a product, the following warnings must be declared on the label; polyols: ‘excessive consumption may induce laxative effects’; aspartame or aspartame-acesulfame salt: ‘contains a source of phenylalanine’. With this, those who have conditions such as irritable bowel syndrome, Crohn’s disease or ulcerative colitis may wish to avoid foods which may induce laxative effects as it might negatively trigger their condition (NHS, 2022). Those with phenylketonuria (PKU) may also wish to avoid foods which are a source of phenylalanine as it can lead to a build of phenylalanine in the blood and brain which can be fatal for children with this disorder (HSE, 2021).

With this, it is reported that a growing trend amongst consumers is taking accountability for their health and wellbeing. With this, consumers are actively seeking out healthier options when conducting their grocery shop and looking for ‘clean labels’ (Saraiva *et al.*, 2020). Interestingly, Milner *et al.* (2020) carried out a study of clean-label sweeteners as a means of reducing the sugar content of cakes, and found that sugar-reduced cakes prepared with whey permeate, oligofructose and polydextrose achieved similar physical properties as that of the control cake, which was prepared with sugar, in terms of crumb

hardness, moisture and water activity (a_w). The authors reported that in all cakes, the interior crumb structure was unaffected by the clean-label sugar replacers and concluded that it is possible to reduce the sugar content of cakes without impacting on taste or overall structure of the cake. In relation to specific volume, the cake prepared with apple pomace was found to have reduced specific volume when compared with the control, which was deemed to be significantly different ($p=<0.05$). The authors reported that this may be due to the fact that apple pomace contains more dietary fibre which may cause the cake batter to hold onto more moisture thus preventing larger bubble formation during the baking stage.

With regard to the finding that polydextrose can achieve physical properties in cakes similar to that of sugar by Milner *et al.* (2020) is supported by evidence from Sahin *et al.* (2019). Sahin *et al.* (2019) discussed how polydextrose is a promising sugar replacer in sugar reduced products due to its ability to aid browning, thus adding to the overall appearance of the cake. Appearance is an important factor which can influence a consumers' intent to purchase. In a survey by the Food Standards Agency (FSA) (2019), it was reported that 31% of consumers were less likely to buy healthier options of cakes. Of those consumers who were less likely to buy healthier cake options, 25% reported that the original options look more appealing. With this, appearance plays an important part in grabbing a consumer's attention in a retail setting so it is important that manufacturers can still achieve a physical appearance similar to that of non-sugar-reduced cakes when reformulating their products. Polydextrose is a long chain polysaccharide which can act as a non-sweet bulking agent in food. However, evidence has shown that it can also lower specific volume and is not capable of replacing the total sweetness lost when sugar is reduced (Sahin *et al.* 2019). In a paper by Kocer *et al*. (2007), it was found that polydextrose has the potential to lower the thermosetting temperature which may explain why previous research has concluded that this ingredient may lower specific volume of cakes.

More recently, sourdough technology has been explored as a more novel approach to reducing the sugar content of cakes. Sahin et al. (2019) demonstrated that

sugar-reduced, high-ratio cakes made with sourdough and fructose are capable of achieving a similar crust to that of cakes made with sugar. For a consumer, appearance is an important aspect when it comes to purchasing and aiding in their overall perception. A brown crust is typically associated with cakes and so it is important that manufacturers can still achieve this. In terms of sweetness, cakes prepared with sourdough were not as sweet as those made with sugar. When fructose was added to the sourdough, this resulted in a slightly sweeter and more aromatic cake. However, the sweetness was still not as close to the sweetness perceived by the cake made with sugar. Fructose triggers mannitol production in the sourdough which is important as mannitol is a polyol and can be used as a sweetener in foods which may explain why these cakes were sweeter than those which contained only sourdough. Interestingly, it seems that cakes which were prepared with commercial mannitol were not as sweet as cakes which consisted of sourdough with added fructose.

Cakes prepared with sourdough were generally more sour than cakes made without sourdough. Despite the fact that cakes prepared with sourdough were rated higher for sourness, cakes that were prepared with sourdough and fructose scored higher than the cake made with sugar for flavour so it is clear that although sourness may be slightly more perceived in these cakes, it did not negatively affect the overall flavour. Texture did not score as well for cakes prepared with sourdough however interestingly, cakes prepared with just sourdough and no fructose, had a softer texture than those with fructose. The researchers concluded that further research is necessary to explore how to improve texture in cakes prepared with sourdough.

Few studies have examined the use of sourdough technology as a means of sugar reduction in cakes. However, Maravic *et al*. (2022) assessed the technological and nutritive effect of sourdough and whey protein on non-sugar reduced sponge cakes and found that spontaneously fermented sourdough contributed towards specific volume and appearance in protein-enriched cakes. The authors also noted that when sourdough was added into the batter at 30%, alongside baking powder, that there was a significant increase in sweetness ($p<0.05$). However, it was noted that sourdough on its

own could not act as a leavening agent, and required the addition of whey protein to create uniform gas bubbles thus impacting on the texture, volume and appearance of the final product. Another study by Zhou *et al*. (2021) studied the effects of sourdough on the physical properties of steamed-cake, which is a traditional cake in China. The authors reported that the textural properties, such as specific volume, hardness and chewiness, of the cake were significantly improved with the addition of sourdough.

Previous studies have evaluated the impact of sugar replacers on the nutritional content of foods. Milner *et al.* (2020) in their study of the use of 'clean label' sweeteners as sugar replacers in cakes, the authors reported a sugar reduction ranging from 21% to 27%, when whey permeate, apple pomace, oligofructose and polydextrose are used as replacers, with oligofructose achieving the highest sugar reduction (27.6% reduction). This demonstrates that it is possible to use clean-label ingredients to reduce the overall sugar content of cakes.

In ROI, Healthy Eating Guidelines advise consumers to limit their intake of foods high in fat, sugar and salt by eating them occasionally and only in small amounts (DoH, 2019). Cakes would fall into this category, however the DoH have not defined a serving size for these types of foods. The WHO recommends that no more than 10% of an adult's daily energy intake should originate from free sugars (WHO, 2015). This thesis analysed the nutritional content of cakes for sale in Dunnes Stores, Tesco, SuperValu, Lidl, and Aldi, and found that the mean value for sugar content of cakes was 35.89g per 100g, while the median value was 36.80g per 100g. Although little information was available on the labels of cake products with regard to recommended serving sizes, it can be calculated based on nutrition information gathered as part of this thesis that the mean sugar content accounts for 34.51% of the mean total energy intake of cakes on the Irish market.

In a similar survey carried out in the UK by Hashem et al. (2017), it was found that the average sugar content of cakes in the UK market was 36.6g per 100g. These findings

are not dissimilar and indicate that cakes available in the ROI and UK markets are similar in their composition.

Public Health England reported concerns from the food industry whereby manufacturers believed sugar reduction in cakes would pose too challenging, as it may lead to an increase of another target nutrient, such as fat, saturated fat or salt (PHE, 2017). This thesis examined if there was a correlation between decrease in sugar content and an increase in another nutrient. The results found that when the sugar content of cakes changes, it does not result in a change in another nutrient. It is interesting to note that when sugar is reduced, that manufacturer's do not appear to increase another nutrient in order to make the product seem 'tastier' or more 'luxurious' to the consumer.

Another finding from this thesis, is in relation to nutrition claims on cakes on the Irish market. From the 234 cake products sampled as part of this study, there were no nutrition claims, relating to energy or sugar, declared on the labels of cake products. In the EU, there is a list of authorised nutrition claims relating to energy and sugar. It is possible that the reason for this is because food businesses do not meet the criteria laid down in the conditions of use for each authorised nutrition claim. According to a survey into consumer perceptions of reformulated bakery products in NI, it was reported that 75% of consumers would purchase cakes which were reduced in sugar (FSA, 2019). Of the 25% who would not purchase cakes which were reduced in sugar, 76% said taste was their reason for not purchasing (FSA, 2019). It is also reasonable to believe that because cakes are considered a once-off treat, that food businesses acknowledge that consumers are more willing to eat more caloric food products, knowing that it would be a once off treat, and with this, they do not want to highlight any nutritional claims so consumers do not view their product as less tasty than other products.

As part of a randomised controlled trial by Franco-Arellano *et al.* (2020) which assessed consumers' perceptions of products healthfulness in the presence of front-of-pack (FOP) labelling and nutrition claims, the researchers concluded that FOP labelling enables consumers to make informed decisions when choosing healthier products and

enables consumers to perceive a product's healthfulness. In both healthier and less healthy drinks, there were no significant differences detected when both products carried nutrition claims, with the authors concluding that nutrition claims had little influence on consumer purchase intentions.

In a study by Mai and Hoffman (2015), they assessed how labelling and composition of food products can influence tastiness and health perceptions of health conscious participants. When using yoghurts as the food product, the authors reported that health conscious participants perceived regular yoghurt as less healthy than yoghurt labelled 'reduced sugar' while less health-conscious participants did not perceive regular yoghurt as less healthy than yoghurt labelled with 'reduced sugar'.

In a systematic review of the impact of nutrition claims on food choices, the researchers reported that nutrition claims relating to sugar content can influence on consumers' perception of the food product's healthfulness and expected tastiness, whereby consumers expect food products with nutrition claims to be healthier and less tasty (Oostenbach *et al.*, 2019). The researchers also noted that food products bearing nutrition claims can influence the purchase intent of consumers based on their health consciousness.

There are several limitations that manufacturers must consider when reformulating their products. In one study, it was highlighted that the limits to food reformulation centre around consumer acceptance, safety aspects, technological challenges and food legislation (van Raaij, Hendriksen, and Verhagen, 2009). The authors highlighted that for salt, reformulation should be introduced gradually in order to accustom consumers to the lower salt content. They note that if the reduction in a nutrient is done too quickly, this will have a negative impact on consumer's intent to purchase due to their perceived noticeable change in sensory attributes (van Raaij, Hendriksen, and Verhagen, 2009). In relation to safety aspects, van Raaij, Hendriksen, and Verhagen (2009) noted that some nutrients play a key role in ensuring or prolonging the safety of a product, for example salt has a preservative effect on food which will need to be taken into account

when reformulating. Technological challenges refer to the roles of certain nutrients in the manufacture of foods so it is necessary that these roles are taken into consideration when carrying out reformulation. Lastly, food legislation relates to the requirement of certain foods to contain a certain ingredient so as not to mislead the consumer, so with this it can be challenging to reduce a target nutrient when the main source of the nutrient can not be replaced from a legal perspective.

Chapter 6: Conclusion and Future Work

6.1 Conclusion

Sugar is an important ingredient in the manufacture of cakes, however sugar is associated with an increase in the prevalence of overweight and obesity in Ireland, which can lead to the development of NCDs. The food industry has been identified as one of the key sectors which contribute to overweight and obesity in the Irish population, and with this food reformulation has been selected as one of the strategies employed in reducing the incidence of overweight and obesity. Consumption of cakes has been identified as a key food category and thus a voluntary reformulation target has been set to reduce the sugar content of cakes by 20% by 2025.

This thesis presented an overview of the strategies in which manufacturers can reduce the sugar content cakes, from an ingredient perspective as well as from a labelling perspective. Sugar has a number of functionalities in the processing of cake, as well as on the final product, with the literature demonstrating that there is no one ingredient that can replace all of the functions of sugar. Therefore, careful consideration must be given to sugar replacers in terms of their physical functionalities and contribution to sensory attributes, as these are important factors when it comes to overall consumer acceptance and the product's success in a competitive retail market.

The research question presented in this thesis was whether it is possible for manufacturers to reduce the sugar content of their cake products, in response to reformulation strategies. This thesis also assessed cakes from a nutrition and labelling perspective to determine if there were any opportunities available to manufacturers. To conclude the thesis, the literature demonstrates it is possible to reduce the sugar content of cakes using food additives, such as non-sweet bulking agents, sweet bulking agents, and high-intensity sweeteners. Evidence suggests that the use of a sweet bulking agent on its own or the use of a non-sweet bulking agent in conjunction with a high-intensity sweetener may be used to achieve sugar reduction. No single additive can replace all of the functions of sugar, however xylitol, which is a sweet bulking agent, proved to be a promising ingredient. Xylitol was found to replace the total sweetness of

sugar, whilst having no negative impact on specific volume or crumb texture. However, xylitol did not contribute to the overall browning of the cake so consideration needs to be given to an ingredient which can add that benefit. Although food additives may help reduce the sugar content of cakes, they have been associated with negative health effects and may be a deterrent for health-conscious consumers when they are declared on food labels alongside their associated E-number.

'Clean label' ingredients such as whey permeate, polydextrose, and oligofructose may be considered as potential sugar replacers in cake products however consideration needs to be given to their dietary fibre content as this may result in too much moisture being retained in the product, resulting in unacceptable quality and sensory attributes.

Sourdough technology is a novel area of reducing the sugar content of cakes, as when sourdough and fructose are used in harmony, it can result in the production of natural mannitol which can add more sweetness to cakes than when cakes are produced using commercial mannitol.

Nutrition claims are under-utilised on cakes in the Irish retail market. There is a gap in the market for healthier alternatives when it comes to cakes and claims surrounding energy and sugar content may help a product to stand out from other products. However, it is important that if a nutrition claim is being used, that the physical and sensory attributes of the product must be appealing enough to influence the consumers intent to purchase.

To conclude, food additives can be successful sugar replacers however, manufacturers may need to use two different food additives in order to replace the full functionalities of sugar. Sourdough is a novel approach to sugar reduction in cakes, and may fit into the trend towards a 'clean-label'. An assessment of cakes for sale in Ireland, showed that manufacturers are not using nutrition claims on their products. There is consumer demand and a gap in the market for healthier cake alternatives. The findings of this thesis are novel as this is the first study of its kind to look at reformulation of cakes in

Ireland from both and a composition and labelling perspective, as well as assessing the nutritional status of cakes currently available on the Irish market. Studies were selected and analysed to demonstrate how sugar could be reduced using sugar replacers and novel approaches. The scope of the studies predominantly focused on the effects of strategies to reduce sugar in terms of their contribution to physical and sensory attributes. This thesis analysed studies from a manufacturing perspective to understand how food businesses can achieve sugar reduction across their range of cake products, in order to meet voluntary reformulation targets.

6.2 Future Work

This study was focused on strategies to achieve sugar reduction in cakes. As highlighted in case studies from the UK, many food businesses are reducing portion sizes of their products in order to reduce the sugar content of cakes. This study focused on sugar content (g per 100g) rather than on sugar content (g per serving). Further studies should assess the impact of portion size reduction of cakes on sugar intake.

In addition, silent reformulation is a popular means of reformulation, whereby sugar is reduced in a product without it being highlighted to the consumer. Although this thesis demonstrated that food businesses do not use nutrition claims to highlight sugar reduction in their products, it is possible to assume that manufacturers may be opting for the silent reformulation approach. Future work should assess how consumers view silent reformulation of cakes.

Lastly, this study discussed the use of food additives, sourdough technology, and nutrition claims as a means of reducing the sugar content of cakes. However, this study did not assess the cost of these ingredients or the cost of re-labelling to the manufacturer. With raw material costs increasing globally, future work should examine the cost of reformulation of cakes.

Chapter 7: References

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