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Interesterified fats: What are they and why are they used? A briefing report from the Roundtable on Interesterified Fats in Foods

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Abstract

Interesterification rearranges the position of fatty acids within triacylglycerols, the main component of dietary fat, altering physical properties such as the melting point and providing suitable functionality for use in a range of food applications. Interesterified (IE) fats are one of a number of alternatives which have been adopted to reformulate products to remove fats containing *trans* fatty acids generated during partial hydrogenation, which are known to be detrimental to cardiovascular health. The use of IE fats can also reduce the saturated fatty acid (SFA) content of the final product (*e.g.* up to 20% in spreads), while maintaining suitable physical properties (*e.g.* melt profile). A novel analysis was presented during the roundtable which combined data from the UK *National Diet and Nutrition Survey* (2012/2013–2013/2014) with expert industry knowledge of the IE fats typically used in food products, to provide the first known estimate of population intakes of IE fats among UK children and adults. IE fats were found to contribute approximately 1% of daily energy across all ages. The major contributors to overall IE fat intakes were fat spreads (~54%) and bakery products (~22%), as well as biscuits (~8%), dairy cream alternatives (~6%) and confectionery (~6%). Increasing use of IE fats could contribute towards reducing total SFA intakes in the population, but would depend on which food products were reformulated and their frequency of consumption among sub-groups of the population. Studies comparing the effect of IE and non-IE fats on markers of lipid metabolism have not shown any consistent differences, either in the fasted or in the postprandial state, suggesting a neutral

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effect of IE fats on cardiovascular disease risk. However, these studies did not use the type of IE fats present in the food supply. This issue has been addressed in two studies by King's College London, which measured the postprandial response to a commercially relevant palm stearin/palm kernel (80:20) IE 'hard stock', although again no consistent effects of the IE fat on markers of lipid metabolism were found. Another study is currently investigating the same IE hard stock, consumed as a fat spread (blended with vegetable oil), and will measure a broader range of postprandial cardiometabolic risk factors. However, further long-term trials using commercially relevant IE fats are needed. Subsequent to the roundtable, a consumer survey of UK adults (n = 2062; aged 18+ years) suggested that there is confusion about the health effects of dietary fats/fatty acids, including *trans* fats and partially hydrogenated fats. This may indicate that providing evidence-based information to the public on dietary fats and health could be helpful, including the reformulation efforts of food producers and retailers to improve the fatty acid profile of some commonly consumed foods.

Keywords: cardiovascular disease, fat metabolism, interesterified fats, postprandial metabolism, saturated fatty acids, *trans* fatty acids

Introduction

Interesterification is a means of modifying the structure and functionality of fats and oils to produce food ingredients for a range of applications, which can help to reduce levels of saturated fatty acids (SFA) and *trans* fatty acids (TFA) in some foods, by providing an alternative to the use of animal fats or partially hydrogenated oils, respectively. The use of interesterified (IE) fats has increased in recent years, as part of the ongoing reformulation initiative undertaken by food manufacturers. A 1-day roundtable event was organised by the British Nutrition Foundation (BNF) and King's College London in March 2019 to discuss the use of IE fats in the food chain, current understanding as to their health effects, and recommendations for future research and communication to key stakeholders. This was arranged within the 'Pathways to Impact' activities of a research grant awarded to King's College London and the Quadram Institute by the Biotechnology and Biosciences Research Council (BBSRC) Diet and Health Research Industry Club (DRINC). Thought leaders from a range of fields, including public health and academia, food retail, manufacturing and technology, were invited to provide expertise and insight to the roundtable discussion. This report provides a summary of the presentations and discussions held at this roundtable meeting.

Cardiovascular disease (CVD) is a major public health issue and accounts for 31% of all deaths globally (WHO 2017). In the UK alone, it is estimated that over 7 million people are living with heart and circulatory diseases (BHF 2019). There are several established and emerging dietary and lifestyle risk factors for CVD. Among these, dietary fat composition has long been considered as important (Sacks *et al*. 2017; Stanner & Coe 2019). For example, TFA produced by partial hydrogenation have also been shown to adversely affect cholesterol levels and CVD risk (Mozaffarian *et al*. 2006).

A diet containing foods high in SFA is associated with a raised serum low-density lipoprotein cholesterol (LDL-C) concentration (Sacks *et al*. 2017), which is a causal risk factor for the development of atherosclerosis and CVD (Peters *et al*. 2016; Ference *et al*. 2017). Dietary advice to reduce SFA intake in order to reduce CVD risk has been established for a number of decades, although this advice has been challenged by meta-analyses of prospective studies showing no relationship between SFA and the risk of coronary heart disease (CHD; Siri-Tarino *et al*. 2010; Chowdhury *et al*. 2014). However, a Cochrane systematic review of 15 randomised controlled trials, involving almost 60 000 participants, concluded that reducing SFA intake significantly reduced the risk of cardiovascular

events by 17%. The review found greater reductions (27%) in cardiovascular events in studies that replaced SFA by polyunsaturated fatty acids (PUFA) than in studies with replacement with carbohydrate (CHO) or protein, where there was little evidence of any effect (Hooper *et al*. 2015). These findings emphasise that the nutrient replacing SFA in the diet is important. Replacing SFA with *cis* configuration unsaturated fatty acids (UFA), and especially PUFA, leads to a reduction in serum LDL-C levels (Mensink 2016). In addition, replacing SFA with UFA may also have benefits on other risk factors including inflammation, endothelial function and platelet activity (see Fig. 1; Stanner & Coe 2019). Other factors which may also be important determinants of the association between SFA and CVD include the specific effects of different SFA on lipid markers of CVD risk (some raise, while others have a neutral effect on LDL-C and total cholesterol; see Table 1; Mensink 2016). The influence of the food matrix, within which SFA are found, is also important; for example, milk and milk products contain saturates but also contain additional constituents that may result in such foods posing no risk for CHD or even being protective (Buttriss & Coe 2019).

The recommendation to reduce the amount of SFA in the diet was first included in US dietary guidelines in 1961 (Page *et al*. 1961) and has been a core part of national dietary guidelines in the UK since 1974 (COMA 1974). In response to public health recommendations to reduce SFA intake, the use of partially hydrogenated vegetable fats increased during the

Table 1 Characteristics of some fatty acids commonly consumed in dietary oils and fats and their effects on lipid markers

Saturated fatty acids

Lauric acid (12:0): the predominant fatty acid in coconut oil. Considered to raise total, HDL- and LDL-cholesterol and lower TAG concentrations

Myristic acid (14:0): found particularly in coconut oil and milk fat. Considered to raise total, HDL- and LDL-cholesterol and lower TAG concentrations

Palmitic acid (16:0): the predominant fatty acid in palm oil, also found in animal fats and coconut oil. Considered to raise total, HDL- and LDL-cholesterol and lower TAG concentrations

Stearic acid (18:0): found particularly in meat and cocoa butter. Considered to have a neutral effect on serum cholesterol and TAG levels

Unsaturated fatty acids

Oleic acid (18:1,*n*-9): the predominant fatty acid in olive oil, also found in rapeseed oil. Considered to lower total and LDL-cholesterol concentrations

Linoleic acid (18:2,*n*-6): the predominant fatty acid in sunflower oil, also present in corn and soya bean oils. Considered to lower LDL-cholesterol concentrations

Long-chain omega-3s (20:5,*n*-3;22:6,*n*-3): found in fish oils. Considered to lower TAG concentrations

Sources: Mensink (2016); Abdelhamid *et al*. (2018). HDL, high-density lipoprotein; LDL, low-density lipoprotein; TAG, triacylglycerol.

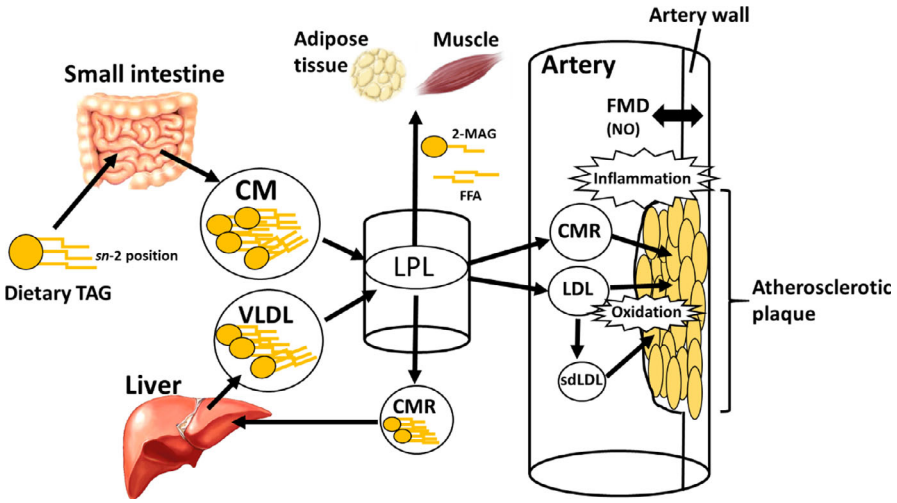

Figure 1 The potential influence of dietary fat on risk factors for cardiovascular disease. Dietary triacylglycerol (TAG) is packed into chylomicron (CM) lipoproteins, which are hydrolysed in the circulation by the enzyme lipoprotein lipase (LPL) to release free fatty acids (FFA) and 2-monoacylglycerol (2-MAG). Chylomicron remnants (CMR) are taken up by the liver or may enter the artery wall and be taken up by macrophages to form 'foam cells', an important component of an atherosclerotic plaque. Very-low-density lipoprotein (VLDL) is produced by the liver and subject to LPL hydrolysis to form low-density lipoprotein (LDL), or the more atherogenic small dense LDL (sdLDL), which is more susceptible to oxidation and therefore uptake by macrophages. Inflammation may also act as a mediator in the development of an atherosclerotic plaque. Flow-mediated dilatation (FMD) can measure the nitric oxide (NO)-mediated ability of the artery to respond (dilate) to changes in blood flow. [Colour figure can be viewed at wileyonlinelibrary.com]

1960s, 1970s and 1980s, to provide an alternative to animal fats or tropical oils rich in SFA (Eckel *et al*. 2007). The process of partial hydrogenation alters the physical properties of an oil high in UFA, increasing its melting point and providing a firmer texture for use in a range of applications (Munday & Bagley 2017). In part, the use of partial hydrogenation was likely a reflection of the popularity of vegetable-derived fats over animal-derived fats in terms of stability, cost, availability and the unique properties these fats could provide, for example, immediate spreadability of margarine from the fridge, compared to the hardness of butter (Eckel *et al*. 2007).

However, the negative cardiovascular health effects associated with consuming oils containing TFA generated during the industrial partial hydrogenation process are now widely recognised (Mozaffarian *et al*. 2006; SACN 2007). This has led to voluntary initiatives and regulatory measures in many countries to decrease so-called 'industrial' TFA in the food chain (Wanders *et al*. 2017). In the UK, voluntary measures by the food industry have resulted in mean TFA intakes in adults and children significantly decreasing. In adults, TFA intakes were reported as 2.2% food energy in 1986/1987, 1.2% in 2000 and further decreasing to 0.5% food energy in 2014/2015–2015/2016 (Gregory *et al*. 1990; Henderson *et al*. 2003; Roberts *et al*. 2018), which is below the recommended maximum for both the UK (<2% of dietary energy; COMA 1994; SACN 2007) and internationally (<1% of dietary energy; WHO 2018). The main dietary source of TFA in the UK diet is now the naturally occurring TFA present in foods derived from ruminant animals – a product of the biohydrogenation process in ruminants – which are considered to be of less concern at the typical levels consumed in the diet (Gayet-Boyer *et al*. 2014; de Souza *et al*. 2015).

In order to reduce 'industrial' TFA in foods, manufacturers have identified and adopted a number of substitutes for partially hydrogenated oils. The use of modified fats and oils with different compositions and desirable functionality and physical properties (*e.g*. melt profile, solid fat content and crystal formation) has allowed a reduction in the use of traditional animal fats from meat and dairy sources, thereby avoiding the use of SFA-rich fats. One of these alternatives is IE fats (Mills *et al*. 2017), which are now used in a wide range of commonly consumed products (*e.g*. fat spreads and cakes) in place of fats and oils higher in SFA and 'industrial' TFA. Given their current use and the potential to expand their usage further in reformulation, it is timely to review current knowledge of the use of IE fats in the food supply and findings from human studies into their potential health effects.

Options for modification of dietary fats and oils

In addition to interesterification, other fat modification methods that avoid the use of partial hydrogenation include blending, fractionation and full hydrogenation. These approaches, summarised in Table 2, have advantages and disadvantages, but, importantly, none alone can deliver the range of functionalities to meet the diverse food applications required by large-scale food production and health-related reformulation strategies.

What is interesterification and why is it used?

In order to understand the process of interesterification, a reminder of basic fat molecular structure is useful. Triacylglycerol (TAG) is the predominant form of dietary fat (~95%) and is composed of three fatty acids esterified to a glycerol backbone (Fig. 2). Each fatty acid can occupy one of three positions, which are referred to using a stereospecific numbering system (*sn*), with the two outer positions referred to as *sn*-1 and *sn*-3 fatty acids and the central position as the *sn*-2 fatty acid. There are several determinants of the physical and biochemical properties of a TAG molecule, including the position (*sn*-1, *sn*-2 or *sn*-3) of its component fatty acids, as well as the chain length of the fatty acids, their degree of saturation (number of double bonds) and their configuration (*cis* or *trans*).

The term 'molecular species' is often used to describe the exact type and position of fatty acids within a TAG molecule. A TAG molecule which only contains SFA palmitic acid (P) and unsaturated oleic acid (O) can have up to eight potential TAG molecular species (POO, POP, OOP, OPO, PPO, OPP, PPP and OOO). Interestingly, plant and animal oils/fats typically differ in the position of UFA and SFA on the glycerol backbone; in plant fats, SFA tend to be attached to the outer *sn*-1 and *sn*-3 positions, whereas animal fats contain a greater proportion of SFA in the *sn*-2 position (Fig. 3). For example, palm oil predominantly contains TAG molecular species with saturated palmitic acid in the *sn*-1 and *sn*-3 positions and unsaturated oleic acid in the *sn*-2 position. However, in lard, the majority of *sn*-2 position fatty acids are palmitic acid, with the greatest proportion of *sn*-1 and *sn*-3 positions occupied by oleic acid (Berry 2009).

Table 2 A comparison of the advantages and disadvantages of natural and modified fats and oils (information presented at the Roundtable on Interesterified Fats in Foods)

Type of fat or oil	Description	Advantages	Disadvantages
Animal fats	Examples include: • lard • beef tallow	• Perceived as 'natural' • Semi-solid at room temperature	• Product not suitable for vegetarians, vegans or other specific dietary requirements (*e.g.* halal and kosher) • May be higher in SFA than vegetable fats • Off flavours which affect taste
Dairy fats	Examples include: • butter • milk fat/cream	• Desirable melt profile for some applications	• Price (5–8 times more expensive than vegetable oil) • Not suitable for all applications (low melting temperature) • Product not suitable for vegans • Typically higher in SFA than most vegetable oils/fats
Interesterified fat	Rearranges the fatty acid composition of TAG, the predominant form of dietary fat, to alter the solid fat content and melt profile	• Does not generate TFA • IE fats can be blended with oils for use in a wide range of applications • Avoids use of alternative fats higher in SFA	• Potential equipment set-up/running costs
Partially hydrogenated oil	Partially hydrogenated oils are defined as oils that have been hydrogenated, but not to complete or near-complete saturation (*i.e.* double bonds are hydrogenated or converted from a cis to trans configuration)	• Uses cheaper vegetable-based oils with a lower SFA content than animal-derived alternatives • Provides fats with a wide range of functionality	• Generates TFA during the hydrogenation process, which remain in the oil as the hydrogenation process is incomplete • Production requires use of metal catalysts
Fully hydrogenated oil	Full hydrogenation of vegetable oils produces fats in which all the fatty acids are fully saturated with hydrogen. Such fats on their own are too waxy and solid to use in many food production applications	• No TFA present in the final product (unlike PHOs) • Can use locally sourced oils (*e.g.* rapeseed oil) • Can be stearic acid-rich (neutral effect on LDL-C) if derived from oils such as rapeseed or soya oils that are rich in 18-carbon fatty acids	• Poor textural qualities (*e.g.* does not melt in the mouth) • May be higher in some SFA that have adverse CVD health effects (see Table 1) • Consumer resistance to products with 'hydrogenated' on food label • Manufacturing difficulties due to high melting points (above 80°C) • Production requires use of metal catalysts
Blended oils	Different base stocks are mixed together to obtain a specific composition, consistency and/or stability in the final product	• Cost-effective • Good consumer acceptance	• Oils used have a higher SFA content than IE equivalents • Crystallisation properties may not always be ideal
Fractionated oils	Separates fats and oils into two or more fractions (*e.g.* palm olein and palm stearin from palm oil) with different melting points. The palm oil industry uses fractionation to alter and extend the functionality of palm oil for use in different food and feed applications	• Most fractionations do not require use of additional chemicals	• All fractions are used and enter food supply chain – no decrease in overall SFA consumption at a population level • Poor crystallisation properties that affect product stability (*e.g.* 'blooming' of fat)

CVD, cardiovascular disease; IE, interesterified; LDL-C, low-density lipoprotein cholesterol; PHO, partially hydrogenated oil; SFA, saturated fatty acids; TAG, triacylglycerol; TFA, *trans* fatty acids.

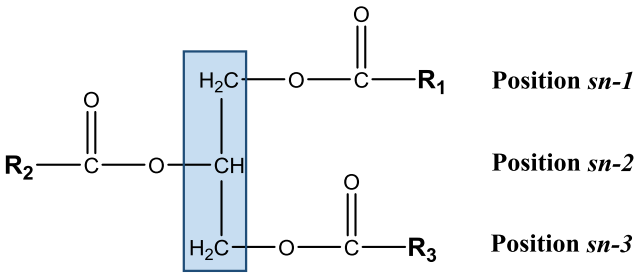

Figure 2 General structure of a triacylglycerol (TAG) molecule. Fatty acids (R_1, R_2 and R_3) vary in their length and degree of unsaturation at each of the three stereospecific positions (*sn*-1, *sn*-2 and *sn*-3). The shaded area represents the glycerol 'backbone' of the molecule. [Colour figure can be viewed at wileyonlinelibrary.com]

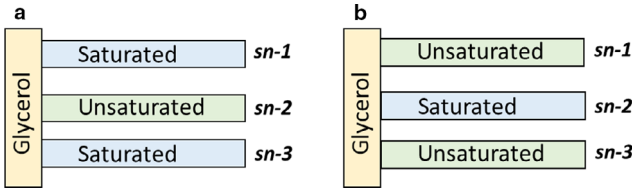

Figure 3 Example of the typical positional arrangement of saturated and unsaturated fatty acids within TAG from plant- (a) and animal-derived fats (b). Based on information from Berry (2016). [Colour figure can be viewed at wileyonlinelibrary.com]

The term interesterification refers to a chemical or enzymatic process that rearranges the fatty acids on the glycerol backbone of a TAG molecule, in either a random or a specific way. The altered proportions of TAG molecular species that result from rearrangement can confer useful functional characteristics, including a higher melting point and altered crystalline structure, and typically increases the solid content of a fat. Position-specific enzymatic interesterification can also be used to create infant formula products with specific TAG molecular species, which mimic the composition of human breastmilk and may aid fat absorption (Spurgeon *et al*. 2003).

Chemical interesterification typically uses sodium methoxide as the catalyst and involves hydrolysis and random redistribution of all fatty acids within a TAG mixture. Chemical interesterification has been in commercial use since the 1940s, when it was used to modify the solid fat content of lard as a means of improving its spreadability and baking properties (Mensink *et al*. 2016). It remains the main form of interesterification used in the UK.

Enzymatic interesterification uses microbially sourced lipase enzymes (*e.g*. from *Candida rugosa*) and gives either a random or specific redistribution of fatty acids, depending on the specificity of the lipases used (Mensink 2016). Enzymatic interesterification was first developed in the early 1980s to provide a cheaper source of confectionery fat to replace cocoa butter, by modifying the TAG molecules within palm oil (Dayton 2014) and has subsequently become the predominant interesterification method used in the US and Canada. While enzymatic interesterification may have lower equipment costs than chemical interesterification, it requires the use of a more expensive catalyst (lipase enzyme compared to sodium methoxide). However, enzymatic methods can be carried out at lower operating temperatures, lead to lower neutral oil losses and preserve the oxidative stability of the resulting product (Rousseau & Marangoni 2002).

As well as differences between the US and the UK in the methods employed for interesterification, different oils are used in the preparation of IE fats, which reflect those commonly used in the food supply. In the US, stearic acid-rich IE fats (soybean oil-based) are used for many products such as baked goods, whereas in Europe palmitic acid-rich fats (palm oil-based) are more common for these applications. Within both Europe and the US, palmitic acid- and lauric acid-rich IE fats are generally used for spreads, due to their enhanced melting properties (see Table 1 for information about these individual fatty acids). In the UK, for example, combinations of palm oil fractions (palm kernel and palm stearin) are used to produce an IE hard stock, which can then be blended at varying ratios with a liquid oil (*e.g*. rapeseed oil) to achieve the desired functional properties (Mills *et al*. 2017).

Key sensory characteristics of the final fat blend, such as the 'mouthfeel', are determined by the melt profile, which reflects the solid fat content at different temperatures. Blending IE fats with liquid oils not only allows suitable functionality but, perhaps more importantly from a health perspective, also results in a final product with a lower SFA content. As an illustration, combining 75% IE palm oil with a liquid oil (*e.g*. rapeseed) can achieve the same melt profile as 'native' palm oil, while reducing the SFA content by 20% (Fig. 4).

How much interesterified fat do we eat in the UK and in which foods is it present?

IE fats are now being used around the world in the manufacture of a range of products, in place of TFA-containing fats, yet there is currently no published estimate of their intake from the UK diet. Assessing intake is not straightforward, requiring specialist knowledge, as many IE fats used commercially are blended with other unmodified oils prior to use.

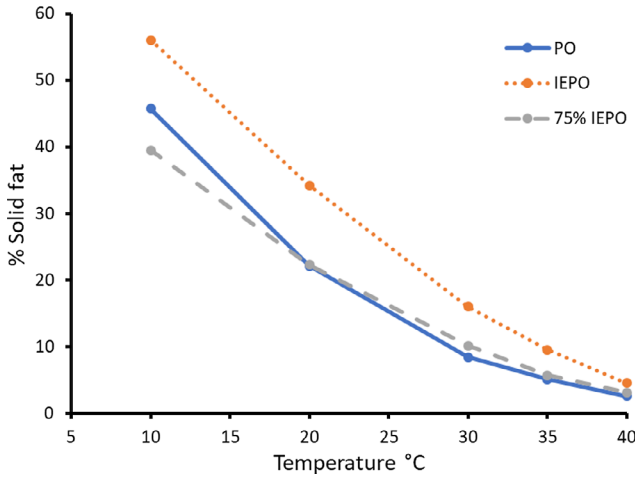

Figure 4 Change in the percentage of solid fat with temperature in three oils. Palm oil (PO); interesterified palm oil (IEPO); IEPO blended with liquid oil (75% IEPO). (Unpublished data: J. H. Bruce, S. E. Berry & W. L. Hall). [Colour figure can be viewed at wileyonlinelibrary.com]

Laboratory analysis can determine the positional composition of the TAG components of a fat, although it may not be possible to quantify what proportion has undergone interesterification and how much is from unmodified oil added to the blend.

To date, the best available estimate of IE intakes has been in the US population and employed modelling methods using dietary intake data from the US *National Health and Examination Survey (NHANES)*. This analysis forecasted the potential IE fat intake if palm-based oils (some of which may be IE), or an IE fat made with fully hydrogenated soybean oil, were used as functional replacements for TFA-containing oils in 12 food categories included in the *NHANES* survey (Mensink 2016). It was estimated that such a scenario would result in an IE fat intake of approximately 3% of daily energy. However, this modelling approach is less helpful in the UK and other European countries because TFA-containing fats in the food supply have already been partly replaced with palmitic acid-rich IE fats.

During the roundtable, a new detailed analysis was presented, which used a novel methodology to estimate current IE fat intakes in the UK population for the first time (unpublished data: J. H. Bruce, S. E. Berry & W. L. Hall). The analysis combined data from the *National Diet and Nutrition Survey* (*NDNS*) with expert industry knowledge of commercially relevant IE fats and their use. The *NDNS* programme is a continuous, cross-sectional survey designed to collect detailed, quantitative information on the food consumption of the general population living in private households in the UK (Bates *et al.* 2016). Food diary intake data from Years 5 to 6 of the *NDNS* Rolling Programme (2012/2013 and 2013/2014) for children and adults (aged 1.5 years and over) were used, the latest raw data that were available at the time of commencing the analysis. A total of 391 foods likely to contain IE fats were identified from the survey data. By applying expert industry knowledge about the type and amount of IE fat blends typically used for each food type (32 potential formulations), it was possible to estimate an IE fat content per 100 g of fat in each case. Using this procedure, a total IE fat intake per day (percentage of energy) was calculated (shown by quartiles of intakes; Fig. 5), as well as the main food groups contributing to IE fat intakes (Fig. 5).

Mean IE fat intake was estimated to be 1.1% (95% CI 0–3.45 %) of daily energy intake in the UK diet (unpublished data: J. H. Bruce, S. E. Berry & W. L. Hall), which equated to a mean (95% CI) IE fat intake of 2.2 g/day (0–6.9 g). In comparison, data for fat intakes from *NDNS* for adults (aged 19–64 years) were as follows: total fat 67.8 g/day (±25.7 g/day); SFA 25.2 g/day (±10.8 g/day); and TFA 1.0 g/day (±0.5 g/day). Those in the highest quartile of intakes obtained a mean 2.4% of energy from IE fats, relative to a mean of only 0.1% of daily energy for people in the lowest quartile of consumption (Fig. 5).

The *NDNS* analysis revealed that the largest food contributor to IE fat intakes was fat spreads, which provided approximately 54% of the total IE fat consumed across all age groups combined (Fig. 6a). Other

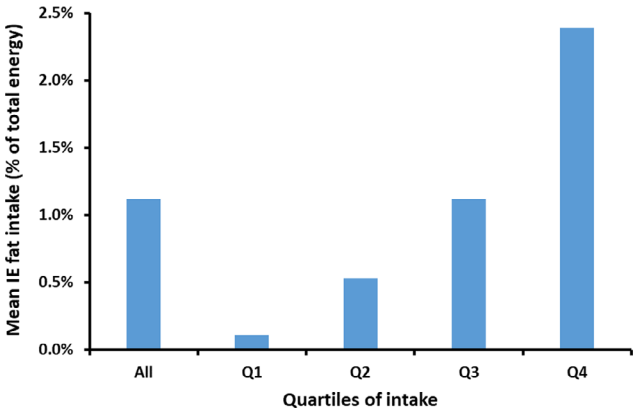

Figure 5 Daily contribution of interesterified (IE) fats to total energy intake (%) for adults and children (aged 1.5 years and over) by quartiles (Q) of IE fat intake using data from the *National Diet and Nutrition Survey* (Years 5 and 6, 2012/2013 and 2013/2014), Bates *et al.* (2007). (Unpublished data: J. H. Bruce, S. E. Berry & W. L. Hall) *More details regarding the data analysis can be requested from the corresponding author.* [Colour figure can be viewed at wileyonlinelibrary.com]

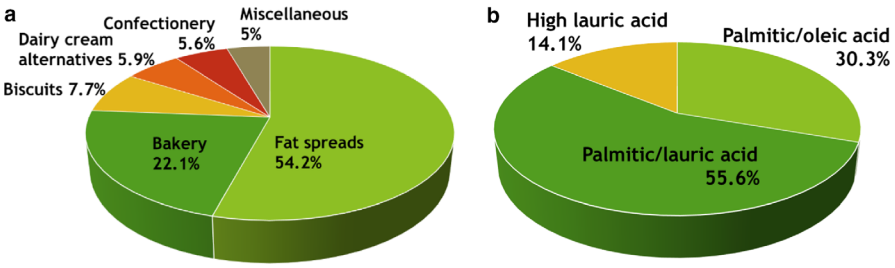

Figure 6 Percentage contribution of different food categories (a) and types of interesterified (IE) fat (b) to overall IE fat intakes among adults and children (1.5 years and over), using data from the National Diet and Nutrition Survey (Years 5 and 6, 2012/2013 and 2013/2014), Bates *et al.* (2007). (Unpublished data: J. H. Bruce, S. E. Berry & W. L. Hall). [Colour figure can be viewed at wileyonlinelibrary.com]

key dietary sources of IE fats were cakes, pastries and bakery goods, contributing approximately 22% of IE fat intake, as well as biscuits (~8%), confectionery (~6%) and dairy cream alternatives (~6%) (unpublished data: J. H. Bruce, S. E. Berry & W. L. Hall). Considering that particular types of IE fats are used for certain food applications (*e.g.* palmitic/lauric acid-rich IE palm oil, blended with vegetable oil, for fat spreads), it is perhaps not surprising that the proportion of IE fat types consumed in the diet reflected the foods in which they are used (Fig. 6a,b). Thus, the highest intakes were of palmitic/lauric IE fats (in fat spreads; around 55%), followed by palmitic/oleic IE fats (in bakery products; 30%), with high lauric IE fats (in buttercream-like fillings, confectionery fillings and chocolate alternatives) comprising the remainder of the IE fat consumed. The data suggest that higher occupational social class may be associated with lower IE fat intakes, but further analysis is required to confirm this.

It is interesting to note that there are strict European regulations (reflected in UK law) determining the type of fats permitted for use in chocolate. Aside from a minimum percentage of cocoa butter requirement, only six types of vegetable fats (illipe, palm oil, sal, shea, kokum gurgi and mango kernel) are authorised for use and must be obtained only by the processes of refining, fractionation or both, which excludes enzymatic (or chemical) modification of the TAG structure (HMSO 2003). Therefore, IE fats may not be used in chocolate but can be used for chocolate-flavoured confectionery fillings or coatings.

Although the UK government's reformulation drive in the last few years has focused largely on sugar reduction, the Scientific Advisory Committee on Nutrition (SACN) report 'Saturated fats and health' published this month (https://www.gov.uk/government/publications/saturated-fats-and-health-sacn-report) draws attention to the importance of reducing the SFA content of food products. One of the important considerations, discussed by the roundtable participants, was the role that IE fats have already begun to play in reducing SFA and 'industrial' TFA intakes in the UK and elsewhere, and the potential to further reduce SFA by wider use in the food chain.

A modelling exercise (unpublished data: J. H. Bruce, S. E. Berry & W. L. Hall) was undertaken to consider the impact of replacing IE fats with the best available non-IE options (*e.g.* fractionation and blending; see Table 2), for each application that is currently using IE fats/oils. As shown in Figure 7, this predicted that the SFA content, as a percentage of total fat, would increase by 11.1 percentage points for fat spreads, 9.2 percentage points for bakery products and 15.7 percentage points for confectionery. The estimated effect of these changes, based on consumption data from the same *NDNS* data set, would be to slightly increase total SFA intake in the population (all ages) from approximately 12.7% to 13.1% of food energy. However, it is likely that the increase in SFA intake would be greater for the highest IE fat consumers.

While removing IE fats from foods and replacing them with non-IE alternatives might increase SFA

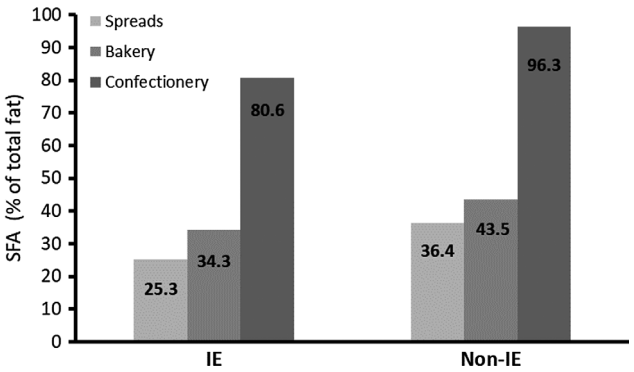

Figure 7 Estimated effect on saturated fatty acid (SFA) intakes of removing interesterified (IE) fats from foods and replacing these fats with non-IE fats (unpublished data: J. H. Bruce, S. E. Berry & W. L. Hall, presented at Roundtable on Interesterified Fats in Foods). *More details regarding the data analysis can be requested from the corresponding author.*

intakes in the population, the greater use of IE fats (*e.g.* as part of a reformulation strategy) could have the opposite effect and further reduce SFA in certain products. A further modelling analysis was performed, again using expert industry knowledge, which estimated that maximising the use of IE fats could reduce the SFA content of biscuits from 47.2% to 36.6% (10.6 percentage point reduction). In terms of other food categories, greater use of IE fats has the potential to reduce the SFA content of cakes and shortcrust pastries from approximately 42% to 35% (of total fat), with little or no change achievable for puff pastry, spreads or confectionery (unpublished data: J. H. Bruce, S. E. Berry & W. L. Hall). The overall effect these changes could have on population SFA intakes would depend on how the amount and frequency of consumption of these products vary among different groups within the population. In this context, it is important to review the research into the effects of IE fats on health, both in the short- and in the long-term, as is discussed in the next section.

What are the health effects of interesterified fats?

The association between SFA, TFA, PUFA and monounsaturated fatty acids has been studied in relation to CVD risk, and their effects on serum lipoproteins have been evaluated (Mensink *et al.* 2003, 2016; Mozaffarian *et al.* 2006). However, the health effects of IE fats, especially those that are commonly used by the food industry, are less well studied.

Interesterification involves positional changes of fatty acids on the glycerol backbone. As a result, while the total fatty acid composition of an IE fat is identical to that of a non-IE fat, the *sn*-positional composition and physical characteristics are different. The cardiovascular effects of different IE fats are likely to be influenced not only by the particular fatty acid composition of the IE fat, but also by the melting point and the percentage of SFA at the *sn*-2 position of TAG, which may influence their absorption and subsequent metabolism (Berry 2009).

It is thought that differences in *sn*-positional composition between some animal and plant fats may explain their divergent effects on atherogenesis (the formation of fatty plaques in the arterial wall; see Fig. 1), despite having a similar SFA content. For example, in palm oil, SFA make up 49% of the total fat and are mainly present in the *sn*-1 and *sn*-3 positions of TAG molecules (only 10% of palmitic acid is found in the *sn*-2 position; Filippou *et al.* 2014b). However, in lard, although the SFA content is similar (44% of total fat), a greater proportion of the SFA are located in the *sn*-2 position (71% of palmitic acid; Filippou *et al.* 2014a).

The pancreatic lipases which digest dietary TAG preferentially release fatty acids attached to the *sn*-1 and *sn*-3 positions of TAG, giving two free fatty acids and a molecule of 2-monoacylglycerol (Yang & Kuksis 1991), which are then absorbed. Commonly consumed SFA (*e.g.* palmitic and stearic acids) may be better absorbed when they are retained within 2-monoacylglycerol during digestion, which has been shown in studies of rats (Brink *et al.* 1995) and human infants (Carnielli *et al.* 1996). Following digestion and absorption, 2-monoacylglycerol is used to re-synthesise TAG, which is then released into the circulation within chylomicron lipoproteins. Circulating TAG containing a higher proportion of *sn*-2 SFA may not be cleared from circulation as efficiently (Mortimer *et al.* 1988) and may lead to the accumulation of smaller chylomicron 'remnants' (Mortimer *et al.* 1990), which are implicated in forming atherosclerotic plaques (Karpe *et al.* 1994; Pal *et al.* 2003; Botham 2008). Furthermore, SFA attached to the *sn*-2 position may be more likely to be transported to the liver, rather than stored in adipose tissue, which may elevate LDL concentrations (West & Fernandez 2005). Therefore, as interesterification of plant oils typically increases the proportion of SFA in the *sn*-2 position, it has been suggested that IE fats may have adverse effects on lipid metabolism and CVD risk.

Feeding studies conducted in both rabbits (Kritchevsky *et al.* 2000a, 2000b) and mice (Afonso *et al.* 2016) have reported more severe atherosclerosis when animals were given diets with IE palm oil, containing more *sn*-2 palmitic acid, compared to native palm oil. However, due to the practical and cost implications of conducting such studies in humans, research to date has instead focused on lipid markers (*e.g.* LDL and total cholesterol) of CVD risk. Several human studies have investigated the effects of consuming IE fats for 3–6 weeks on fasting measures of blood lipids [total cholesterol, high-density lipoprotein cholesterol (HDL-C) and LDL-C; TAG], in comparison with non-IE equivalents. None of these studies reported any significant effect when participants consumed IE palm oil (Zock *et al.* 1995; Nestel *et al.* 1998; Filippou *et al.* 2014b), IE shea butter (Berry *et al.* 2007a), IE butter (Christophe *et al.* 2000), IE lard (Shane *et al.* 1999) or an IE blend of fats (Meijer & Weststrate 1997), relative to a native test fat equivalent. It is possible, though, that the relatively short duration of these

trials and the limited number of subjects may have been insufficient to detect a significant effect on fasting lipid profile. In addition, the IE fats used in these studies are not those used commercially.

While measuring fasting lipid parameters provides some useful information, most humans eat several times a day and spend the majority of their time in the postprandial (fed) state. An elevated postprandial lipaemia (as indicated by the size or duration of the increase in plasma TAG concentrations following a meal) is associated with an increased risk of cardiometabolic disease, which includes CHD (Eberly *et al*. 2003; Bansal *et al*. 2007). Other than the influence on lipoprotein re-modelling, postprandial lipaemia may also increase CHD risk through oxidative stress, inflammation, haemostatic perturbations and endothelial dysfunction (Marchesi *et al*. 2000; Bae *et al*. 2001). Thus, determining the postprandial response to different dietary fats may be a more important tool for predicting cardiometabolic risk than fasting lipid concentrations.

A number of studies have been performed to assess whether interesterification may adversely affect postprandial lipid or glucose metabolism, although the results have not indicated any detrimental effects (see Table 3). While some acute studies have suggested a neutral effect on postprandial lipaemia, glucose and/or insulin concentrations (Zampelas *et al*. 1994; Summers *et al*. 1998, 1999; Yli-Jokipii *et al*. 2003; Filippou *et al*. 2014b), other studies have reported a reduced postprandial TAG response to an IE test fat (Yli-Jokipii *et al*. 2001; Sanders *et al*. 2003, 2011; Berry *et al*. 2007b; Robinson *et al*. 2009; Hall *et al*. 2014). The inconsistency in these postprandial effects reported in studies was discussed at the roundtable. A plausible explanation raised was the suggestion that the solid fat content may be a more important determinant of the digestion and metabolic handling of a fat than the positional composition (the proportion of fatty acids at the *sn*-2 position; Berry 2009). Different TAG molecular species (*e.g.* POP vs. PPO) appear to be digested and metabolised at similar rates in humans. However, TAG species in which interesterification imparts marked differences in physical characteristics are likely to form micelles less readily, which may slow their rate of digestion and absorption in the intestine.

A key limitation of the postprandial studies of IE fats described in Table 3 is that the IE fats tested were not representative of those that are used commercially and that are present in the food chain, therefore limiting the public health relevance of the findings. To address this issue, researchers from King's College London conducted two studies to investigate the effects on postprandial lipid metabolism of a commonly consumed IE hard stock (the hard fat that is blended with other oils/fats) consisting of a blend of IE palm stearin and palm kernel oil. The findings from these studies were presented and discussed at the roundtable. In the first study, a palm stearin/palm kernel (80:20) hard stock, which was either IE (55% palmitic acid in *sn*-2) or unmodified (36% palmitic acid in *sn*-2), was baked into muffins to provide 50 g of each test fat on two separate occasions (Hall *et al*. 2017). The muffins were identical in composition except for the type of fat used and were given as part of a test meal, which also included custard and a milkshake [832 kcal total energy; 15 g protein (7% energy); 81 g carbohydrate (37% energy); and 52 g fat (56% energy)]. In the 12 healthy men studied, there was a significantly greater incremental area under the curve (iAUC) TAG (a measure of the plasma TAG response to the test meal over time; 51% higher) after the IE fat than the non-IE fat. However, the pattern of lipaemia differed in response to the two test meals, with plasma TAG levels declining 4 hours after the meal containing IE fat, whereas they continued to rise until the end of the study period following the non-IE fat test meal. Therefore, despite the greater TAG excursion after the IE palm stearin/palm kernel hard stock, it is possible that values may have returned to baseline more rapidly than for the non-IE hard stock.

In the recently completed *InterMet* study (ClinicalTrials.gov Identifier: NCT03191513), Mills and colleagues tested the same commercially relevant hard stock palm fats, either IE or non-IE, to investigate 8-hour metabolic responses (measured hourly) to a single test meal containing these fats, thus providing novel information on the acute effects of commercially relevant IE fats on postprandial lipaemia (Berry *et al*. 2018). Healthy subjects ($n = 20$; males and females; aged 45–75 years) consumed test meals (muffin and a milkshake; 897 kcal; 50 g fat; 16 g protein; 88 g carbohydrate), which again provided 50 g of the test fat on each occasion. A meal containing a reference fat (rapeseed oil), which was known to elicit a pronounced postprandial lipaemic response, was also tested as a comparator. In contrast to the hypothesis, there was no difference between the IE and non-IE hard stocks noted in postprandial lipaemia values measured at 4 hours (time of peak lipaemia) or 8 hours (reflecting the efficiency of TAG-rich lipoprotein clearance), nor for

Table 3 Summary of studies investigating the postprandial effects of interesterified fats

Study	Subjects and duration	Test fat used	Postprandial effects
Hall *et al.* (2014)	11 males (40–70 years; BMI 20–35 kg/m^2), 6-hour period	75 g of native PO or IPO	Lower plasma TAG response during first 4 hours for IPO test meal vs. PO test meal, no overall differences during 6-hour period
Filippou *et al.* (2014a)	25 males and 25 females (18–45 years; BMI 20–35 kg/m^2), 2-hour period	50 g of high oleic sunflower oil (control), PO, IPO or lard	No differences in response between four test meals for plasma glucose, insulin or C-peptide
Sanders *et al.* (2011)	25 males and 25 females (18–45 years; BMI 20–35 kg/m^2), 8-hour period	50 g of high oleic sunflower oil (control), PO, IPO or lard	Lower plasma TAG response for IPO vs. PO or control
Robinson *et al.* (2009)	11 obese males (mean age 59.3 ± 1.8 years; BMI >30 kg/m^2) and 10 non-obese males (55.8 ± 2.2 years; BMI >30 kg/m^2), 6-hour period	1 g fat/kg body mass blend of non-IE, CIE or EIE sunflower oil/canola stearin	Greater plasma TAG response with CIE vs. NIE in obese subjects. No other differences
Berry *et al.* (2007b)	20 males (18–60 years; BMI 20–35 kg/m^2), 6-hour period	50 g of native PO or IPO	Lower plasma TAG (at 1, 2, 5 and 6 hours) and insulin response (at 30, 90 and 120 minutes) after IPO vs. PO
Berry *et al.* (2007a)	16 males (mean age 26.8 ± 8.0 years; mean BMI 23.7 ± 3.7 kg/m^2)	3 weeks of diet containing 30 g of native or IE shea butter followed by postprandial assessment of response to 50 g of native or IE shea butter	No differences in plasma TAG, insulin or glucose response
Yli-Jokipii *et al.* (2003, 2004)	2 males and 7 females, 8-hour period	55 g of native or IE lard per square metre body area	Almost significantly lower TAG after IE lard vs. native lard
Sanders *et al.* (2003)	17 males (mean age 38.2 ± 11.1 years; mean BMI 24.5 ± 2.9 kg/m^2), 6-hour period	50 g of native or IE cocoa butter	Lower plasma TAG response and lower factor VIIa concentrations after IE vs. native cocoa butter
Yli-Jokipii *et al.* (2001)	10 females (18–45 years; BMI 18.5–25 kg/m^2), 6-hour period	55 g of native or IE lard per square metre body area	Lower plasma TAG response after IE vs. native lard
Summers *et al.* (1999)	14 females (29–70 years; BMI 20.6–52.8 kg/m^2), 6-hour period	60 g of native (67% oleic acid in *sn*-2) or EIE fat (83% stearic acid in *sn*-2)	No differences in plasma TAG, VLDL-TAG, CM-TAG, glucose or insulin responses
Summers *et al.* (1998)	2 males and 6 females, 6-hour period	60 g of native (6% palmitate in *sn*-2) or EIE fat (68% palmitate in *sn*-2)	No differences in plasma TAG, VLDL-TAG, CM-TAG, glucose or insulin
Zampelas *et al.* (1994)	16 males, 6-hour period	40 g of IE blend (palm stearin with sunflower and high oleic acid sunflower oils) or 'native' vegetable oil	No differences for CM-TAG, glucose or insulin

Mean values are ±SD. BMI, body mass index; CIE, chemically interesterified; CM, chylomicron; EIE, enzymatically interesterified; IE, interesterified; IPO, interesterified palm oil; NIE, non-interesterified; PO, palm oil; TAG, triacylglycerol; VLDL, very-low-density lipoprotein.

iAUC values over the 8-hour period. Lipoprotein particle size and number were also determined, and, similarly, no significant differences were found between the IE and non-IE test fats. The results from this study, in addition to the evidence already discussed, do not indicate a negative effect of IE fat consumption on fasted or postprandial markers of cardiometabolic risk.

Despite the apparently neutral postprandial lipaemic response after acute consumption of IE palm-based fats consumed as hard stocks, there may still be differences in postprandial lipaemia and other cardiometabolic risk indicators, such as vascular function, when comparing IE fat-containing products available off the shelf with functional alternatives. For example, commercially, the palm stearin/palm kernel

(80:20) hard stock is often blended with other unmodified vegetable oils (*e.g.* rapeseed) in varying proportions to meet a desired functionality of the end product (*e.g.* 20% solids at 20°C but only 3% solids at 35°C). The postprandial effect of IE fat blends within widely available products is currently being explored by researchers at King's College London, in a further randomised controlled double-blinded study.

The ongoing *InterCardio* study (ClinicalTrials.gov Identifier: NCT03438084) aims to investigate differences in the acute cardiovascular risk response to a widely consumed spread containing IE fat, vs. other non-IE functional equivalents, using multiple biomarkers of CVD risk. In this intervention study, 50 healthy subjects (male and female) are being recruited to consume test meals containing typical retail spreads composed of either IE fats or other non-IE functional equivalents (50 g of each fat), spreadable butter, a non-IE fat equivalent spread and rapeseed oil as the reference fat. In addition to postprandial TAG concentrations, this study will assess vascular function, oxidative stress and inflammatory responses over an 8-hour period. Results of this study will increase understanding of the effects of IE fats on a broader range of cardiovascular risk markers and will help determine whether longer-term chronic dietary intervention studies are needed to fully understand the potential impact on atherosclerosis and cardiometabolic disease risk.

Recommendations for future research

Present knowledge suggests a neutral effect of IE fats on cardiovascular health, but there are research gaps which need to be addressed. Considerations for future studies on the metabolic effects of IE fats were highlighted in a previous expert workshop convened by the International Life Sciences Institute (Mensink *et al.* 2016) and were also discussed at the roundtable (Table 4). Some of the considerations listed in Table 4 reflect advances in our understanding of the breadth of factors which determine overall cardiometabolic risk. In addition to effects on lipid metabolism, this includes consideration of glucose metabolism and insulin sensitivity, as well as inflammatory (*e.g.* C-reactive protein), oxidative stress and haemostatic markers (*e.g.* tissue plasminogen activator). In particular, chronic studies of longer duration using commercially relevant IE fats, of the type and amount typically consumed by the population, are needed. Observational studies investigating the relationship between population IE fat intakes and health outcomes will also add insight.

Table 4 Considerations for the design of future studies on the health effects of interesterified fats

Unknown metabolic effects of interest

- Chylomicron and VLDL lipoprotein production rate, size and remnant clearance, including particle size distribution (*e.g.* proportion of small dense LDL).
- Incorporation of *sn*-2 SFA into phospholipids and effects (*e.g.* HDL function).
- More novel cardiometabolic risk factors: insulin sensitivity; hepatic and other ectopic fat deposition; flow-mediated dilatation.
- Levels of inflammation (*e.g.* C-reactive protein, interleukin-6), oxidative stress (*e.g.* NADPH oxidase) and haemostatic markers (*e.g.* activated factor VII, tissue plasminogen activator, D-dimer).

Study design considerations

- Longer study duration (> 8 weeks) with well-controlled test diets (matched for energy and fatty acid content).
- Use commercially relevant blends of IE fats consumed in the UK diet at appropriate levels (*e.g.* 3–5% of dietary fat) within relevant food products (*e.g.* fat spreads).
- Comparison of effects according to sex, age, ethnicity, body composition (normal weight vs. overweight/obese) and among individuals at increased CVD risk (*e.g.* those with type 2 diabetes).

Source: Mensink *et al.* 2016 and the Roundtable on Interesterified Fats in Foods. CVD, cardiovascular disease; HDL, high-density lipoprotein; IE, interesterified; LDL, low-density lipoprotein; NADPH, nicotinamide adenine dinucleotide phosphate; SFA, saturated fatty acids; VLDL, very-low-density lipoprotein.

Many of the considerations mentioned in Table 4 have been incorporated into the design of the aforementioned *InterCardio* study, including a detailed assessment of the postprandial lipaemic response to test fats (*e.g.* TAG concentrations; chylomicron fatty acid composition; lipoprotein particle size; and number, see Fig. 1), as well as markers of vascular function (*e.g.* flow-mediated dilatation to measure nitric oxide-mediated endothelial function; plasma nitrite and nitrate species), inflammation (*e.g.* plasma interleukin-6) and oxidative stress [*e.g.* nicotinamide adenine dinucleotide phosphate (NADPH) oxidase enzyme]. The chronic postprandial effects of IE fats will also be investigated in an upcoming trial due to begin later this year at King's College London and Maastricht University. The *InterSat* study will involve a chronic 12-week intervention (two 6-week intervention periods; 2-week run-in and 2-week washout; 16 weeks in total) to compare the health effects of two commercially relevant IE fats, which are either palmitic acid- or stearic acid-rich, on a wide range of the cardiometabolic measures discussed. The estimated potential cardiovascular public health impact of consuming IE fats, compared to application appropriate

alternatives, will also be calculated in this body of BBSRC research using data from the *NDNS*, expert industry knowledge and input from collaborators including Professor Ronald Mensink (Maastricht University, The Netherlands).

Building and maintaining links between nutritional researchers and the food industry is essential to ensure the relevance of future studies of IE fats, especially in respect to the type of fats that are used. The BBSRC DRINC initiative is one such example of high quality and innovative research into diet and health resulting from the collaboration between academia and industry, and has led to the funding of the aforementioned *InterMet* and *InterCardio* studies conducted at King's College London. These trials exemplify how partnership working can lead to research that utilises the scientific rigour and expertise of researchers, while ensuring that findings have commercial and public health relevance. In addition, multidisciplinary workshops, such as the roundtable discussed in this paper, which bring together key stakeholders from sectors including higher education, government departments, public sector organisations, health services and industry representatives, should also be encouraged to increase the effectiveness with which research is conducted and the findings are disseminated.

Communicating about interesterified and other dietary fats

A review of nutrition and health research published in 2017 by the Office for Strategic Coordination of Health Research suggested that the public's trust in nutrition science has been eroded in recent years and that many people may feel confused about current nutrition and dietary advice (MRC 2017). This may in part be due to an over-reliance on nutrition and health stories reported in the wider media, where the findings from scientific studies may be exaggerated, sensationalised or even misreported. Taking dietary SFA as an example, there has been recent debate about the relationship between SFA intake and CVD risk, perhaps with insufficient acknowledgement of the need to consider the nature of the nutrients replacing SFA in the diet and the influence of the food matrix in which SFA are consumed. Appreciation of the complexities of the inter-relationship between dietary components and health has led experts to suggest that more practical food-based dietary advice is needed, rather than focusing on individual nutrients. This change in thinking has been summarised recently (Buttriss & Coe 2019).

While providing consumers with advice about healthier dietary patterns is important, reformulation of products by food manufacturers and retailers (*e.g.* to decrease SFA content) is also likely to have an important effect on longer term population health and form a valuable part of a broader, multicomponent public health strategy around food and nutrition. One of the benefits of reformulation is that it does not require people to make a conscious change in behaviour to benefit from the improved nutritional profile of foods, as long as they continue to buy the reformulated products. However, reformulation can be challenging for manufacturers and retailers, as while most consumers are interested in making healthier food choices (IGD 2019), flavour remains the strongest determinant of food choice (Webb & Byrd-Bredbenner 2015; IFICF 2018). Maintaining palatability as well as other important physical and sensory properties is therefore essential.

Although IE fats have been utilised to reformulate a number of commonly consumed food products, their contribution to daily energy intakes remains low. However, as an increased use of IE fats is a potential means to decrease SFA levels in the food supply, it is insightful to have information about public awareness and perception of the term 'interesterified fats' in relation to other types of fat/fatty acids. King's College London and the BNF therefore commissioned a YouGov online survey (April 2019), which provided up-to-date information on the attitudes of 2062 British adults (aged over 18 years). The reported awareness of different fat/fatty acid types among the survey respondents is shown in Figure 8.

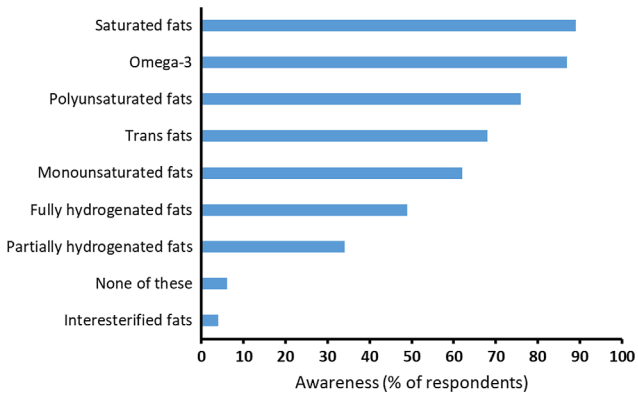

Figure 8 Consumer awareness of different types of dietary fat and fatty acids from an online survey (April 2019) involving 2062 British adults. (Source: YouGov Plc). Figures have been weighted and are representative of all British adults (aged over 18 years). [Colour figure can be viewed at wileyonlinelibrary.com]

Table 5 Consumer perception of the healthiness of different fat and fatty acid types from an online survey (April 2019) involving 2062 British adults

	'Healthy' (%)	'Unhealthy' (%)	'neither healthy nor unhealthy' (%)	'Don't know' (%)
Interesterified fats	1	18	8	73
Partially hydrogenated fats	2	32	18	48
Saturated fats	3	69	10	19
Fully hydrogenated fats	3	40	13	44
Trans fats	4	50	13	33
Monounsaturated fats	17	23	17	43
Polyunsaturated fats	29	17	20	34
Omega-3	85	1	5	9

Source: YouGov Plc. Figures have been weighted and are representative of all British adults (aged 18+ years).

The survey did not gather information on people's understanding of these terms, although they were asked to categorise how healthy they considered these fats/fatty acids to be (see Table 5). A higher proportion of respondents considered 'fully hydrogenated fats' to be unhealthy (40%) than 'partially hydrogenated fats' (32%), which indicates confusion among consumers about the difference between these two processes and the relative health effects of the fats they produce. It is possible that many of the respondents attached a negative connotation to the term 'hydrogenation' and assumed the 'full' process to be worse than a 'partial' one, although it is the latter that generates TFA.

As is evident from Figure 8, fewer respondents were aware of 'partially hydrogenated fats' (34%) than '*trans* fats' (68%) and a smaller proportion considered them unhealthy (32%), relative to '*trans* fats' (50%). This suggests a lack of awareness of 'partially hydrogenated fats' as a source of '*trans* fats' among UK consumers. In the US, requirements for the labelling of TFA on food products and restrictions on the use of partially hydrogenated oils in foods have been introduced as measures to reduce TFA intakes, which are higher than in the UK. In contrast to the situation in the US, the voluntary reformulation by food manufacturers of products sold in the UK over a number of years has led to a significant decrease in TFA intakes, with current intakes below recommendations.

Almost a fifth of adult respondents in the survey perceived 'interesterified fats' to be 'unhealthy' (18%), while approximately three-quarters (73%) stated that they 'don't know', and a further 8% categorised them as 'neither healthy nor unhealthy' (Table 5). This is perhaps not surprising, as intakes of IE fats are generally low and they have not been reported in the media. Taken together, the findings shown in Table 5 suggest understanding of the relationships between different types of dietary fat and health is limited.

The potential task of improving the public's understanding of dietary fats in general, IE fats in particular, and the pros and cons of different reformulation options, was discussed during the roundtable. An important issue highlighted is the increasing popularity of so-called 'clean' labels on food products (Osborn 2015). Although there is no strict definition of what constitutes a clean label, this typically refers to products which contain a short list of 'natural' or 'kitchen cupboard' ingredients, products which are free from additives or preservatives, and those which are produced with limited processing (Asioli *et al.* 2017). In a UK survey conducted in 2016, foods which were rated by participants as more processed were viewed as being less healthy (EUFIC 2016), although understanding improved when participants were provided with scientific information on the potential benefits of food processing, such as improved food safety and nutritional quality.

Considering that the IE fats typically used in the UK are palm oil-based, the relevance of negative consumer perceptions of palm oil sustainability was discussed by the roundtable participants. UK imports of sustainable palm oil, supported by the Roundtable on Sustainable Palm Oil (RSPO) certification, increased from 24% in 2009 to at least 87% in 2015 (Defra 2017). This increase was largely the result of an industry-led commitment made by various stakeholders in the palm oil supply chain (*e.g.* oil processors and distributors, food and drink manufacturers and retailers). A YouGov survey of 1695 UK adults, conducted in March 2016, indicated that 41% of respondents considered palm oil to be 'environmentally unfriendly', a higher proportion than for all other types of vegetable oil included in the survey (*e.g.* 15% for 'soybean oil') (Ostfeld *et al.* 2019). There was also very low recognition of the RSPO 'ecolabel' trademark (5% of respondents), which can be used on products containing at least 95% RSPO certified palm-derived components (RSPO 2016). This may suggest that public opinion is lagging behind progress and change in the palm oil market.

The roundtable participants agreed that, given the apparent confusion among consumers about the relative healthiness of different types of dietary fat (and modification techniques used to provide functional

fats, such as hydrogenation), it would be pertinent to prioritise communication between scientists, healthcare professionals and non-specialists in the food industry, to ensure a consistent knowledge of the interesterification process, and the evidence to date on the health effects of IE fats. Members of the roundtable also highlighted the following points for consideration before any future wider communication to the general public about IE fats.

- There is a need to understand better consumers' attitudes and information needs with respect to interesterification and other commonly used food processing techniques, including whether there is a less technical term that could be used for IE fats (*e.g.* 'mixed' or 'random' fats). This could be achieved through the use of surveys (as reported here) or consumer focus groups.
- As the acceptance of processed foods may increase when consumers are given information on the potential benefits of food processing (*e.g.* improved food safety and enhanced nutritional profile), highlighting the benefits of using interesterification as a food technology (removal of TFA and reduction in SFA content) could help consumers to form a balanced opinion of the use of IE fats. However, it was agreed that more research is needed on the longer-term health effects of commercially available IE fat products.
- Communication about IE fats could provide an opportunity for food manufacturers to build trust with their consumers through information about how food products are produced, and the reasons for using particular processing technologies.
- Concise summary information for non-technical staff within food businesses may be useful.
- Enzymatic interesterification of fat occurs in the body during the production of human breast milk (Miles & Calder 2017). This could be utilised as an example of 'natural' interesterification to explain the process to consumers.
- Research to date on the metabolic effects of IE fats indicates a 'neutral' effect on cardiometabolic risk, although further long-term human studies of commercially relevant IE fats are needed. This could present a challenge for communication, as public uptake of nutrition messages is generally better if they carry a specific 'doable' recommendation (Webb & Byrd-Bredbenner 2015).
- There is no legal requirement to specify the use of an IE fat as an ingredient on the label of a food product. The roundtable participants agreed that, at present, there is no scientific evidence to suggest that this would be useful information for the consumer. However, focusing communication on stakeholders in the food industry, those working in public health and other healthcare professionals, would increase the level of understanding of interesterification, should any consumer concerns arise in future.

Conclusion

Interesterification is a technique that provides fats which can be used in a range of food applications. It is one of a number of reformulation approaches that have enabled the removal of partially hydrogenated fats and 'industrial' TFA from the food chain, without altering key product characteristics such as flavour and cost. The use of IE fats can also result in a final product with a lower SFA content, in comparison with using the currently available non-IE alternatives. The novel data presented in this paper indicate that daily intakes of IE fats are relatively small among UK consumers (about 1% of daily energy intake on average). There is the potential to increase their use in certain product categories (*e.g.* cakes and biscuits). Further reformulation of these product types could potentially contribute to reducing population intakes of SFA, alongside recommendations to encourage healthier dietary choices. However, achieving this would depend on the amount and frequency with which IE-containing products are consumed by different groups within the population. The limited research to date in humans suggests no adverse effects of consuming IE fats on cardiometabolic risk, and longer term studies using commercially relevant IE fats are underway.

Results from the survey presented in this paper indicate confusion about the health effects of dietary fats among the UK public. This offers an opportunity to provide the public with factual information about dietary fats and health, as well as the reformulation options and new technologies that are being employed to improve the fatty acid profile of many food products. Such an approach might be an important public engagement strategy to enable better understanding of the science around dietary fats and health, and the reformulation journey that has been under way for some decades, geared to improving public health.

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Conflict of interest

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