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REVIEW

Feasibility of recommending certain replacement or alternative fats

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Expert groups and public health authorities recommend that *trans*-fatty acid (TFA) intakes from industrially produced partially hydrogenated vegetable oils (PHVOs) should be less than 1% of total energy intake. The starting point for any regulatory or nonregulatory response to this recommendation is to assess the extent of the problem by determining where in the food supply TFAs are found and the amounts consumed in the population. Unfortunately, this is a particularly difficult task using traditional methods of dietary assessment inasmuch as food composition databases with TFA data are either nonexistent or incomplete in most countries. Current evidence on estimates of intake suggests there is high variability in TFA intakes and their food sources between countries. The ubiquitous presence of PHVOs in the global food supply in bakery products, deep-fried foods, snack foods, confectionery products and table spreads attests to their commercial value and convenience. However, their common use is more the result of historical convenience from an industry infrastructure developed over 50 years based on efficient, cost-effective hydrogenation of vegetable oils rather than any inherent sensory or physical superiority of the hydrogenated fats over purpose-made zero-*trans* fats and oils. Current global supply of appropriate zero-*trans* replacement fats high in *cis*-unsaturated fatty acids is insufficient to meet the demand if all PHVOs in the food supply were replaced. Regulatory action needs to be coordinated with supply to maximize the opportunity for health gains by replacing partially hydrogenated fats with purpose-ready zero-*trans* vegetable oils low in saturates and high in *cis*-unsaturates rather than animal fats and tropical oils high in saturated fatty acids.
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Introduction

The Joint WHO/FAO Expert Consultation on Diet, Nutrition, and the Prevention of Chronic Diseases recommended that the mean population intake of *trans*-fatty acids (TFAs) from industrially produced hydrogenated oils and fats should be less than 1% of energy (WHO, 2003). This recommendation was based on an extensive body of epidemiological and experimental evidence concerning the health effects of TFAs, evidence that is readily accessible through the scientific literature. However, evidence on which to judge the feasibility of recommending particular replacement or alternative fats is not as accessible or of similar quality. A significant body of information about the global production of replacement fats and their physical and sensory properties is proprietary. With the exception of a few countries, food composition databases do not contain TFA data; consequently, estimates of population intakes of TFAs are based on methods of dietary assessment that involve considerable assumptions, are of low quality and precision, may be inaccurate and are costly. Evidence from nutrition surveys can be used to identify foods and food groups in different countries that are likely to represent important sources of industrially produced TFAs; however, the rate of product reformulation with new fats and oils that is occurring in the food manufacturing and food service industry poses particular challenges to know where TFAs are in the food supply and for monitoring the impact of any recommendations to reduce intakes. Regulatory actions taken by governments to reduce TFAs in the food supply are in their infancy, having come into force only recently. It is important for populations and individual health that TFAs, when removed from the food supply, be replaced by *cis*-unsaturated fats from vegetable oils rather than saturated fats from tropical oils or animal fats. Thus, regulatory approaches to reduce or eliminate TFAs need to be accompanied by measures to

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educate and encourage manufacturers to use preferentially *cis*-unsaturated fatty acids instead of only tropical oils and animal fats. Industry-led initiatives exist and the most successful was with spreadable vegetable fats and margarines, where TFAs were dramatically decreased in the products without increasing saturated fat composition. In general, the monitoring of the impact of removing TFAs from the food supply on the type of replacement fats has been nonsystematic and opportunistic, and unable to provide quantitative evidence on what is being used. Future monitoring needs to be considerably more systematic.

For the purpose of this report, unless otherwise specified, TFAs refer to those from partially hydrogenated vegetable oils (PHVOs). The reduction in the food supply of TFAs of animal origin does not require specific regulatory measures inasmuch as their removal is the inevitable consequence of reducing saturated fats of animal origin in the food supply.

Assessing *trans*-fatty acids intakes

The starting point for any regulatory or nonregulatory response to TFAs is to know where in the food supply these fats are found and the level of consumption in the population. Furthermore, strategies to reduce the use of industrially produced TFAs in the global food supply will require monitoring to determine the impact of the initiatives on TFA and saturated fat intakes.

Per capita food consumption

At the most basic level, accurate information about the supply and distribution of PHVO combined with information about the TFA composition of these oils would enable crude estimates of changes in the availability of industrially produced TFAs to be calculated. Such information would often be reported as food disappearance data, food availability data or per capita food consumption data. In practice, it appears that few countries include TFAs as a 'core nutrient' in food disappearance data reports. For example, in the United States, the Department of Agriculture each year reports per capita consumption of total, saturated, monounsaturated and polyunsaturated fat but not *trans* fat (TF), although it is possible to obtain information about per capita consumption of margarine and shortening (United States Department of Agriculture, 2007). However, the TFA composition of the margarine and shortening can only be assumed.

The major limitation with food disappearance data, even if international information on TF was readily available, is that per capita food consumption only measures the availability of food in the population, not the actual consumption. If the population target of less than 1% of energy from *trans*-fatty acids is applied to individuals, monitoring compliance will require dietary assessment of individual intakes of TFAs so that a measure of the variability in intakes can be estimated.

Dietary assessment with dietary records, recalls or food frequency questionnaires

Assessing TFA intake in populations requires two major types of information: the first is usual food and beverage consumption, for example, that collected during national nutrition surveys using dietary recalls, records or food frequency questionnaires; the second is a food composition database that includes the TFA composition of foods. The food composition database is used to convert food and beverage consumption into intakes of TFAs. The greatest limitation to assessing population intakes of TFAs is that few countries have a food composition database that contains the TFA composition of foods; countries that do include the United States, Germany and the United Kingdom. However, the extent to which these databases reflect up-to-date TFA composition of the food supply is questionable (Table 1). *Trans*-fatty acids have been reported in the United States Department of Agriculture National Nutrient Database since 1994, but values have been derived from nationally randomized food sampling only since 2004. Furthermore, the data

Table 1 *Trans*-fatty acid (TFA) data in food composition tables

Limitations	*Recommendations*
• Incomplete and questionable accuracy of nutrient database for TFA composition of foods due partly to wide variability in TFA content among individual foods within a food category, for example, breads—large variation between brands	Ongoing sampling and analysis of foods
• TFA content for a specific brand within a geographical area may vary over time due to food manufacturers changing the type of oil used in response to availability, cost and current supplier	Essential that TFA content of individual foods be linked with brand name in the food composition tables
• Food composition databases may lack the ability to provide precise estimates of TFA intake for foods consumed	Essential that databases be updated with values for specific foods, by brand or by the fats and oils in the product to give accurate estimates of TFA intakes of individuals
• Independent approaches between countries are required to take into consideration the different nutrient compositions of food products, that is, Australia/New Zealand differ from North America and Europe	Country-specific food composition databases are a prerequisite for estimating TFA intake by dietary assessment

set is not complete for TFAs, with only 800 foods having derived values (Eckel *et al.*, 2007). Even when the relevant database includes TFAs, obtaining accurate estimates of intake is difficult because the food that an individual consumes may not have been prepared with the same type of fat as the matching food in the database. For example, Innis *et al.* (1999) reported that in Vancouver, Canada, the TFA content of 14 different brands of crackers ranged from 1 to 13 g per 100 g cracker, and 19 brands of cookies ranged from 0.3 to 8.1 g per 100 g cookies. In most databases, there would not be a data line for each brand of food, at best there may be a few brand-specific lines and a composite of different brands. A similar variability was reported by Satchithanandam *et al.* (2004), who found that the TF content of tortilla and potato chips in the Washington DC, USA area varied from 0 to 17 g per 100 g chips.

This 'hidden' fat is derived predominantly from manufactured foods and foods prepared outside the home (Elias and Innis, 2002). Furthermore, manufacturers often reformulate their foods with new types of fats and oils, according to price, supply and other market factors, making it difficult to ensure that the TFA data in the food composition database are current. For example, it has been estimated that in the United States Department of Agriculture National Nutrient Database, 50% of the 800 foods with analytical values have been reformulated since being added to the database (Eckel *et al.*, 2007). In countries where TFA labelling becomes mandatory, food manufacturers will, as they have in the United States, be stimulated to reformulate and replace TF with other fats. Given the time and resources required to sample, analyse and update foods in the database, it is unlikely that more than 10–20% of TFA data in food composition databases could be updated in any one year with analytical values. For example, the New Zealand food composition database has approximately 100 foods sampled and analysed each year; the database contains full nutrient profiles for approximately 1700 foods. A recent programme in Canada to monitor how industry has responded to government guidelines to reduce TFA levels in manufactured foods provided valuable information that the TFA composition of selected foods was decreasing (L'Abbé *et al.*, 2009). However, the survey was conducted using a food-sampling protocol that was not sufficiently representative of the national supply to allow the analytical data to be included in the national food composition database.

The large variability in the TFA content of the same food between brands, the lack of brand-specific lines in food composition databases, as well as the difficulty in updating the food composition database with reformulated products make it difficult to obtain accurate estimates using dietary recall, records or food frequency questionnaires on the distribution of individual intakes of TFAs in the population.

In the absence of a full dataset of the TFA content of foods, an alternative approach to estimate population TFA intakes based on nutrition surveys is to impute and assign each food in the food composition database a TFA content. This method has been used recently by Food Standards Australia New Zealand (2007). The approach uses results from national nutrition surveys or market share data to identify food groups that are likely to be major sources of TFAs in the diet, often because the food group accounts for a high proportion of total fat intake. A number of foods considered representative of each food group are selected for TFA analyses, or values are taken from available and published sources. Foods not analysed are assigned the mean value of analysed foods in that food group. In the case of the modelling work done by Food Standards Australia New Zealand, the total number of foods for which analytical values were available was approximately 150, representing less than 10% of the number of foods in the food composition database that were used to model TFA intakes; all other foods had imputed values.

The challenges faced by high-income countries to maintain a food composition database that has complete fatty acid data exemplifies that for most countries in the world accurate assessment of TFA intake through traditional methods of dietary assessment will be difficult if not impossible.

To estimate TFA intakes in 14 Western European countries, van Poppel (1998) used a 'market basket' approach to select, in each country, a maximum of 100 foods representative of fat intake and contributing to 95% of total fat intake. For each country, the TFA content of the foods was combined with results of dietary assessment surveys to generate an estimate of total TFA intake. This method was similar to that employed by Food Standards Australia and New Zealand; however, the variability of the TFA content of a given food between manufacturers or food institutions was not accounted for inasmuch as only one sample of each food was analysed.

There are a large number of assumptions that must be made in using incomplete food composition databases to estimate population intakes of TFAs, but if the range of foods analysed is typical of TF-containing foods, the overall estimate of TFA intake may be reliable. With hindsight, the approach may have proved adequate in Australia and New Zealand because the analysed composition of manufactured foods showed a narrow range of TFA content of foods; up to five brands of the same food were analysed to obtain a range (Wijesundera *et al.*, 2007). In countries, for example, Canada (Health Canada, 2006), where the use of partially hydrogenated fats with very high TFA content may be more common, the range of TFA content of foods is likely to be much higher and the population estimate of TFA intake using this approach less reliable.

In any country, methods based on incomplete food composition data will be of limited value in assessing the variability of TFA intakes in the population and, therefore, in monitoring the proportion of the population with TFA intakes less than a particular target, for example, one per cent of energy intake.

Mandatory nutrition labelling of the TFA content of foods is required by the Food and Drug Administration in the United States when a food contains more than 0.5 g of TFAs per serving (Food and Drug Administration, 2003). The regulation requires that the TFA content, reported on the nutrition label, be determined by 'appropriate and reliable analytical methods'. Thus, there is the potential to link manufacturer's data on the TFA content of foods with the United States Department of Agriculture National Nutrient Database. However, in practice, the lack of standardization of food-sampling methods and analytical methods between food manufacturers and governmental database authorities makes such a linkage difficult.

Estimates of *trans*-fatty acid intake from national surveys

A summary of estimated intakes of TFAs in different countries is shown in Table 2; some of the results are based on indirect dietary assessment techniques modelled on national survey food intake data. Mean TFA intakes from ruminant and industrially produced sources range from a low of 0.6% of total energy in Australia to a high of 4.2% of energy in Iran. In an adult person, 1% of total energy corresponds to about 2.5 g of TFAs.

In what foods or food groups are *trans*-fatty acids found?

It is important to understand which foods or food groups are important sources of industrially produced TFAs inasmuch as this knowledge can inform and target the choice of regulatory or nonregulatory action. For example, if the majority of TFAs come from foods prepared in foodservice establishments, such as fast foods, rather than from manufactured foods, a TFA labelling regulation is unlikely to cause the foodservice industry to reduce their use of PHVOs because the industry, for practical reasons, is not required to use food labels. Although there are data on TFA intakes worldwide, much of these data are out of date and may provide a misleading picture of the major food groups that contribute to TFA intakes in different countries. Over recent years, in some countries, there has been significant reformulation of food products and enhancements made in food technology in response to the pressure on food manufacturers and governments to remove TFAs from the food supply.

Recent evidence suggests that there is tremendous variation between countries in the food sources of TFAs. Even the same food item produced by the same manufacturer or foodservice establishment differs markedly between countries. Stender *et al.* (2006a, b) in a survey conducted between November 2004 and February 2006 of Kentucky Fried Chicken and McDonald's french fries and chicken nuggets from 26 different countries found that the TFA content of a large serving of McDonald's fries varied from less than 1 g in Denmark and China to 8 g in South Africa; a McDonald's meal consisting of a large serving of fries and large serving of chicken nuggets varied from less than 1 g in Denmark and China to more than 10 g in the United States. The between-country variation of a Kentucky Fried Chicken meal of french fries and chicken nuggets was even larger, with less than 1 g of TFAs in Germany and India to more than 20 g in Hungary and Bulgaria (Stender *et al.*, 2006a, b). Of note, 90%

Table 2 Intake of industrially produced *trans*-fatty acids in different countries

Source	*Country*	*Ruminant (%)*	*Industrially produced TFA (%)*			*Mixed (%)*	*% Total energy*
			Total	*Fastfoods*	*Spreads*		
Food Standards Australia New Zealand (2007)[a]	Australia	60	24	8–24		16	0.6
Food Standards Australia New Zealand (2007)[b]	NZ	41	46	3–16		13	0.7
Health Canada (2006)[c]	Canada	19	81	22	37		2.2
Stender and Dyerberg (2004)[d]	Denmark	50	50				1
Food and Drug Administration (2003)[e]	US	21	79	—	17	—	2.6
van de Vijver *et al.* (2000)[f]	Europe						0.9
Hulshof *et al.* (1999)[g]	Europe						1–2
Food Standards Agency and the Department of Health (2003)[h]	UK				18		1.2
Mozaffarian *et al.* (2007)	Iran						4.2

[a]Dietary modelling (DIAMOND) using nutrition survey data from 1995 NNS combined with concentration data from New South Wales Food Authority 2005, South Australia Health 2002 and FSANZ 2001–06.
[b]Dietary modelling (DIAMOND) using nutrition survey data from 1997 combined with concentration data from Institute of Environmental Science and Research Limited 2006 and Crop and Food Research 2002.
[c]Dietary intake data from nutrition surveys conducted in Ontario, Manitoba, British Columbia and Quebec collected during 1997–99.
[d]National food consumption data for men and women 19–64 years. Matched with laboratory analysis of major foods. Based on TRANSFAIR, 1996.
[e]Estimates based on 1994–96 USDA Continuing Survey of Food Intakes by Individuals, 1995 USDA database of TFA content and other data not specified.
[f]Cross-sectional study; eight European countries ($n=626$), 50–65 years old.
[g]TRANSFAIR, 14 Western European countries.
[h]2000–01 National Diet and Nutrition Survey of 19–64-year-old individuals.

of the french fries and chicken nuggets analysed by Stender *et al*. (2006b) were made from fat containing more than 2% industrially produced TFAs, and 50% of the foods exceeded 5 g per serving (Table 3). Katan (2006) reported that McDonald's French fries from the Netherlands had less than 4% *trans* (g/100 g fatty acids) in comparison with a mean of 20% *trans* in French fries from six different cities in the United States. Results from the TRANSFAIR study also showed large variations in the TFA composition of French fries, popcorn, soup and crackers between 14 Western European countries (Aro *et al*., 1998).

The proportion of TFA intake from different food groups also varies from country to country. The variation not only reflects real differences in the use of partially hydrogenated fats but also differences in the classification of foods into food groups. For example, in the latest United Kingdom National Diet and Nutrition Survey for children (2000) and adults (2003), the majority of dietary TFAs, produced as a result of hydrogenation, were derived from the food groups 'fat spreads' and 'potatoes and savoury snacks'. The 'fat spreads' group included spreading fats, chocolate, biscuits, buns, cakes and pastries, while the 'potatoes and savoury snacks' included fried savoury snacks, such as crisps and popcorn (Minihane and Harland, 2007). Collectively these two food groups contributed 30 and 22% of TFAs to children's and adult's diets, respectively.

A particularly difficult food group is 'fast food'. The definition of what constitutes a fast food is not consistent; in many cases, results of nutrition surveys do not show a breakdown of total or industrially produced TFA intake into a fast-food subcategory. Should the fast-food category be limited to foods bought from a fast-food outlet or should it include foods purchased as 'take-away' from restaurants or purchased frozen and prepared at home? The per cent contribution of food groups to total TFA intake in different countries is shown in Table 4; judgement has been used to condense food-group data from different countries into comparable food groups.

Estimates from nutrition surveys in Canada suggest that fast foods do not account for the majority of TFAs in the diet (Table 2). In the United States, bakery products—including cakes, bread, crackers, pies, cookies, and so on—are the

Table 3 *Trans*-fatty acid content of selected foods from 26 countries

Food	*No.*	*Per cent >2% IP-TFA*	*Serving size*	*Per cent containing TFA (g) per serve*		
				<1 g	*>5 g*	*>10 g*
Fast food	55	90	171 g French fries 160 g chicken nuggets		50	15
Biscuits, cakes and wafers	393	40	100 g		12	3
Popcorn	87	57	100 g	50	50	29

Source: Stender *et al*. (2006a, b).

Table 4 Per cent contribution of food groups to total *trans*-fatty acid intake

Food group	*Percentage contribution of food groups to total TFA intake*					
	UK[a]	*UK*[b]	*NZ*[c]	*Australia*[c]	*US*[d]	*Europe*[e]
Cereal and products[f]	26	28	20	13	34	17
Pastry and pastry mixed foods	—		14	10		4
Milk and milk products	16	17	29	20		18
Egg and egg dishes	3	2	—	—		—
Fat spreads, oils and shortening	18	13	13	38	21	36
Meat and poultry	21	15	13	9		11
Fish and products	3	2	—	—		—
Vegetables[g]	1	—	7	2		—
Potatoes and savoury snacks	6	10	1	2	13	5
Confectionary	4	8	—	3		—
Drinks	0		—	—		—
Other	3	1	3	3		4
Ruminant					21	

[a]UK National Diet and Nutrition Survey, adults 19–64 years (Food Standards Agency and the Department of Health, 2003).
[b]National Diet and Nutrition Survey, young people 4–18 years (Food Standards Agency and the Department of Health, 2000).
[c]Dietary modelling of National Nutrition Survey data (Food Standards Australia New Zealand, 2007).
[d]Estimates based on 1994–96 USDA Continuing Survey of Food Intakes by Individuals, 1995 USDA database of TFA content (Food and Drug Administration, 2003).
[e]TRANSFAIR Study, 14 Western European countries (Hulshof *et al*., 1999).
[f]Includes cakes, crackers, biscuits and cereal-based mixed foods.
[g]Excludes potatoes.

major source of industrially produced TFAs, making up 40% of all TFAs in the diet or 51% of industrially produced TFAs (Food and Drug Administration, 2003; Mozaffarian *et al.*, 2006). In Iran, hydrogenated home-cooking oils are the major source of TFAs (Mozaffarian *et al.*, 2007). The limited information from different countries on the proportion of total hydrogenated TFAs from fast foods suggests that eliminating PHVO from the fast-food industry is important but will not eliminate the majority of TFAs from the food supply. It is, however, worth noting that this consideration applies to mean TFA intakes in a population. The consumption of fast foods is not evenly distributed in the population and may be considerably higher in subgroups that consume a high proportion of manufactured or restaurant foods.

The evidence suggests that there is no single group of foods that, if targeted to be TFA free, would eliminate most TFAs from the international food supply. It is clear that there are tremendous differences between countries in the types of fats and oils used in manufactured foods, foods prepared in foodservice establishments and foods prepared in the home, and these differences may determine the type of action needed in each country to replace TFAs with *cis*-unsaturated fats.

Table 5 Fatty acid composition of vegetable oils and animal fats

Type of oil	*TFA*	*SFA*	*Per cent of total fatty acids*		
			Oleic 18:1	*Linoleic 18:2*	*Linolenic 18:3*
PHVO no. 1 TFA	21	13	49	13	5
PHVO no. 2 TFA	33	14	49	3	1
PHVO no. 3 TFA	43	16	35	5	1
Coconut	tr	91	7	2	tr
Palm	tr	49	40	10	tr
Palm olein	tr	45	42	12	tr
Lard	4	43	42	10	1
Tallow	5	50	42	3	1
Butter	6	68	25	1	2
Sunflower	tr	11	29	60	tr
PH-sunflower	20	12	58	10	tr
HO-sunflower	tr	11	84	5	tr
Soybean	tr	15	24	53	7
PH-soybean	16	16	42	24	2
HO-soybean	tr	38	21	35	6
Canola	tr	6	57	26	9
PH-canola	20	9	61	9	1
HO-canola	tr	6	89	2	3
Peanut	tr	17	52	30	tr
Corn	tr	14	28	57	1
Cotton	tr	27	18	54	1
Safflower	tr	11	13	76	1

Abbreviations: HO, high-oleic acid; PH, partially hydrogenated; PHVO, partially hydrogenated vegetable oil; SFA, saturated fatty acids; TFA, *trans*-fatty acid; tr, trace. Sources: Bayard and Wolff (1996); Lake *et al.* (1996); Liu *et al.* (2002); Crop and Food Research (2004); United States Department of Agriculture (2005); Minihane and Harland (2007); Ratnayake *et al.* (2007).

Nature of replacement fats and oils for partially hydrogenated vegetable oils

Trans-unsaturated fatty acids are produced during the partial hydrogenation of vegetable oils; by controlling the extent of hydrogenation that occurs in the parent oil, manufacturers are able to produce vegetable fats with a range of hardness. Partially hydrogenated vegetable oils have physical and sensory properties, such as increased oxidative stability, that contribute to longer product shelf-life, improved mouth-feel, plasticity and flavour through characteristics such as crispness or creaminess (Jang *et al.*, 2005; Tarrago-Trani *et al.*, 2006; Minihane and Harland, 2007). The ubiquitous presence of PHVOs throughout the global food supply in bakery products (for example, cakes, biscuits, bread, crackers, pies, and so on), deep-fried fast foods, snack foods, confectionery products and table spreads attests to their commercial value and convenience. However, this is more the result of historical convenience from an industry infrastructure developed over 50 years based on efficient, cost-effective hydrogenation of vegetable oils rather than any inherent sensory or physical superiority of the hydrogenated fats over other types of zero *trans* oils with appropriate proportions of saturated and *cis*-unsaturated fatty acids.

The fatty acid composition of a range of vegetable-based oils and animal fats is shown in Table 5; data were compiled from a number of sources (Bayard and Wolff, 1996; Lake *et al.*, 1996; Liu *et al.*, 2002; Crop and Food Research, 2004; United States Department of Agriculture, 2005; Minihane and Harland, 2007; Ratnayake *et al.*, 2007). Partially hydrogenated sunflower and soybean oils have decreased proportions of linoleic acid and increased proportions of oleic acid and TFA in comparison with their parent oils; the saturated fat content is largely unchanged. Lists of substitute fats and oils for partially hydrogenated fats have been published (Tarrago-Trani *et al.*, 2006; Eckel *et al.*, 2007) along with their physical and sensory characteristics, use in the food industry and method of production; this information is summarized in Tables 6 and 7. These replacement fats and oils can be produced by modification of the hydrogenation process, interesterification of different fats to produce a fat or oil with desired fatty acid composition, or fractionation of tropical oils. Oil blends can also be used as replacement fats, for example, a TFA-free blend of palm oil–palm stearin–palm olein as a substitute for high *trans*-vanaspati, a common oil used in the Indian subcontinent (Nor Aini *et al.*, 1999; Bhanger and Anwar, 2004). However, in this example, the replacement blend is high in saturated fatty acids. Some oils are produced from seeds with novel fatty acid composition through traditional plant-breeding techniques or through genetic modification. These oils are often referred to as trait-enhanced or novel oils, containing negligible proportions of TFAs, higher proportions of *cis*-monounsaturated and lower proportions of *cis*-polyunsaturated fatty acid compositions when compared with the PHVOs they are intended to replace (Tarrago-Trani *et al.*, 2006; Eckel *et al.*, 2007; Minihane and Harland, 2007).

Table 6 Characteristics of replacement fats and oils

Alternative fats and oils	*Type of oil*	*Physical property*	*Functionality*	*Application*	*Availability/cost*	*Impact*
Unmodified parent vegetable oil	Soybean and sunflower oil	Highly unsaturated	Very prone to oxidation, short shelf life, undesired texture and taste	Not suitable for deep frying, shortenings, dough and chocolate	Large supply/ moderate cost	
Tropical oils	Palm oil, palm olein, coconut oil and fractionate products	Low in TFA. High SFA	Stable. High melting point. Texture, oxidizability and stability comparable to PHVO	Suitable as frying oil and for shortenings, dough and chocolate	Large supply/ low cost	Increase SAFA in food supply
Nontropical/ naturally stable oils	Corn oil, cottonseed oil	Low linolenic. Cottonseed oil high in saturated fat		Suitable as a replacement for most partially hydrogenated vegetable oils	Limited supply of corn oil, highly influenced by demand for corn feed, starch, biodiesel fuel. CSO available in substantial quantities globally/ moderate cost	
Interesterified oils with vegetable oil	Company-specific products. Canola oil, soybean oil, with palm and palm kernel oils		Does not convert *cis* to *trans* isomers. Can produce high *cis*-unsaturated and low saturated oils	Baking and manufactured products	Limited supply/ high cost	
Proprietary interesterification	Commodity soybean		Uniformity and steeper melting curves, avoids waxy taste of blended liquid oils with stearic acid	Baking—solid fat application	Small supply (>4 years to build infrastructure)	
Modified hydrogenation process	Company-specific products	Lower levels of TFA				
Blending liquid/ soft oils with harder components	Company-specific products HO canola and fully hydrogenated cottonseed oil. Kraft Food Inc. Nabisco Oreos: HO rapeseed and palm olein HO sunflower oil with hand-pressed sesame and rice bran oil		Various fatty acid compositions and melting points. Eliminate TFAs and reduce SFA without sacrificing functionality. Premium quality and meets all characteristics	Frying or baking. Unique product application. TFA-free cookie, frying	Limited supply/ high cost	
Modified/trait-enhanced oils	Mid-oleic corn, soybean and sunflower oils, high-oleic canola or sunflower, low-linolenic canola or soybean	High in MUFA or $n-6$ PUFA, small amount of $n-3$ PUFA	High stability. Increased shelf life	Frying	Expanding supply, long development time/high development cost premium price	

Abbreviations: CSO, cottonseed oil; HO, high-oleic acid; MUFA, monounsaturated fatty acids; PHVO, partially hydrogenated vegetable oil; PUFA, polyunsaturated fatty acids; SFA, saturated fatty acids; TFA, *trans*-fatty acid.
Sources: Campbell (2005); Eckel *et al.* (2007); Health Canada (2006); Liu *et al.* (2002); Minihane and Harland (2007); Tarrago-Trani *et al.* (2006).

Table 7 Characteristics of trait-enhanced vegetable oils

Recommended alternative	*Type of oil*	*Physical property*	*Functionality trait, that is, appearance, texture, flavour, stability and nutrient composition*	*Application*	*Availability*
Mid-oleic sunflower[a]	Trait enhanced	65% oleic	Adequate shelf life, resistant to oxidation/rancidity, long fry life	Deep-frying, and frying in food manufacturing (for example, snacks)	Small supply (>4 years estimated to build up infrastructure). Primarily grown for use as edible oils
Oleic (high)	HO sunflower and HO rapeseed/ canola	70–85% oleic acid, <10% of total fatty acids as SFA, <1% TFA	High stability comparable to PHVO	Frying	Limited use by food industries
High-oleic canola/rapeseed	Trait enhanced[b]	High-oleic omega-9	Taste favoured and longer fry life over low-linolenic soybean oil	Frying	Primarily grown in North America and Europe. 1.5 billion lb (2007) (doubled previous years supply)/cost effective
High-oleic sunflower	Trait enhanced[b]	High-oleic omega-9	Meet requirements for commercial frying oils	Frying	Small supply. Primarily grown for use as edible oils. Driven by customer demand. Expired patent means increased production and merchandise
Low-linolenic Soybean[c,d]	Trait enhanced	<3% linolenic acid	Uncompromised taste, acceptable sensory properties	Most frying, spray oil, baking when blended with other oils	1.5 billion lb (2007)[c]. Demand-driven/cost competitive
Low-linolenic/ mid- to high-oleic soybean[c,d]	Trait enhanced	<3% linolenic acid	Uncompromised taste, acceptable sensory properties. Higher stability versus low-linolenic, longer shelf life	Frying, spray oil, baking when blended with other oils	In development, pending FDA/USDA approvals[c] Full availability after 2011[d]
Low-linolenic/ high-oleic/high-stearic soybean[d]	Trait enhanced	High stearic	Produces usable solid fat with minimal saturates (primarily stearates with neutral health effect)	Requiring saturated fatty acids for functionality	Full availability after 2014

Abbreviations: HO, high-oleic acid; PHVO, partially hydrogenated vegetable oil; SFA, saturated fatty acids; TFA, *trans*-fatty acid.
Campbell (2005); Eckel *et al.* (2007); Health Canada (2006); Liu *et al.* (2002); Minihane and Harland (2007); Tarrago-Trani *et al.* (2006).
[a]Archer Daniels Midland.
[b]Dow.
[c]Monsanto.
[d]Pioneer.

Evidence about the sensory and physical properties of these trait-enhanced oils is not extensive in the peer-reviewed scientific literature, likely, the consequence of the proprietary nature of most oils. In the production of modified vegetable oils for replacing partially hydrogenated fats, one of the aims is to reduce the linolenic acid content because this fatty acid is unstable during storage and is readily oxidized, contributing to a rancid, fishy flavour. A search of the scientific literature—using trade names (NuSun, VISTIVE, Omega-9 oils, Natreon, Enova, and so on.)—to gather information about the oxidative stability, flavour characteristics and physical properties of replacement oils resulted in a small number of original articles. Cottonseed oil, with approximately 25% saturated fatty acids, had stability characteristics similar to that of hydrogenated soybean and canola oils under experimental deep-frying conditions and is a reasonable non-hydrogenated alternative for use in foodservice establishments (Daniel *et al.*, 2005; Daniel-O'Dwyer *et al.*, 2007); cost was US$0.13 per kg higher than soybean oil in 2005 (Ash and Dohlman, 2007). Pan-frying characteristics of NuSun, a mid-oleic acid oil, was acceptable (Kiatsrichart *et al.*, 2003). An interesterified palm and cottonseed blend produced good favourable cake characteristics (Dogan *et al.*, 2007).

The published evidence along with advice from industry experts indicates that high *cis*-unsaturated fats and oils with zero TFAs can replace PHVOs without compromising the sensory and physical properties of the food. This is particularly true for spreadable fats with the use of interesterified oils as well as for fats used in deep- or pan-frying where high *cis*-unsaturated trait-enhanced oils or oil blends are acceptable. Furthermore, it is possible to choose replacement fats that have a saturated fat content less than 20% of total fatty acids, a threshold often considered the mark of a low saturated fat oil. In relation to bakery fats, notably food such as cakes, sweet pastry, puff pastry, biscuits and crackers, there is a need for harder fats that maintain the desired functional properties. The range of zero TF, which are low in saturated fats, is limited. The most common substitutes for PHVO in baked goods are tallow, milk fat, palm stearin blends and interesterified fats, all high in saturates. Proprietary information provided to the Scientific Update group showed innovation in the reformulation of bakery foods using high levels of emulsifiers along with zero *trans*, high *cis*-unsaturated and low saturated fat.

Replacing PHVOs with their parent oils—most commonly, soybean, sunflower, canola or fish oils—is a difficult option for the food industry because of the poor oxidative stability of the oils under deep-frying conditions and poor palatability and pliability characteristics of the oils. Unhydrogenated soybean is particularly unsuitable for deep-fat frying due to its high content of linoleic and linolenic fatty acids. Frying with these highly unsaturated fatty acids produces polymeric and polar oxidized materials, which are coming under increasing nutritional scrutiny. A target specification has linolenic acid at a maximum of 2% of total fatty acids. This guideline is legally enforced in France, where the risks from oxidized and polymerized fat used in frying are seen as significant (Piper, 2001).

For the purpose of deep frying, common substitutes include beef tallow or palm olein; cottonseed is also increasingly common. It is possible to blend these oils with trait-enhanced high *cis*-unsaturated oils to reduce the saturated fat content. In fact, the use of proprietary oil blends by fast-food chains is an area of specific activity. The final blend is determined by the choice of fatty acid profile and cost. The New York City Health Board lists a full range of substitute frying fats to guide the restaurant industry's compliance with the ban on TFAs in restaurant foods (New York City Department of Health and Mental Hygiene, 2007a). The New York City Health Board in a press release reported that 94% of restaurants were no longer using PHVOs; however, information about the type of substitute fats being used was not reported (New York City Department of Health and Mental Hygiene, 2007b). In the United Kingdom, it is reported that palm olein comprises 90% of deep frying oil used in the production of crisps (Minihane and Harland, 2007). In New Zealand, a nationally representative survey in 1998–99 indicated that 92% of the frying fats used by fast food and foodservice outlets, as well as industrial fat, were tallow or tallow-based blends; there was little use of PHVOs (Morley-John *et al.*, 2002). Recent data in Canada have indicated that many frying fats in the fast-food industry have been replaced by medium- and high-stability vegetable oils, resulting in a virtual elimination of TF in products fried in these fats and a significant reduction of saturated fats as well (usually by more than 50%). More detailed information on the response of the food industry to removing TFAs in Canada is presented elsewhere in this supplement (L'Abbé *et al.*, 2009). The supply of substitute oils is likely to influence the choice of replacement fats and a transition phase is probably inevitable. The possible evolution of these changes is shown in Table 8.

The wholesale prices in New Zealand for a range of deep-frying fats and oils are presented in Table 9. The high price of trait-enhanced vegetable oils relative to animal fat or palm oil—more than double the price—illustrates that price may be a deterrent, particularly for independent foodservice operators, to the widespread use of novel vegetable oils for deep frying.

With regard to baked products and other manufactured foods high in TFAs, the cost of oils is normally a small

Table 8 Suggested evolution of changing deep-frying fats

Time	*Type of fat used*	Trans	*Saturated*
Traditional practice	Partially hydrogenated oils	30–40%	20%
Present	Blends of palm olein, cottonseed, sunflower seed, canola, and so on	Zero	30–40%
Future	High-oleic forms of sunflower, soybean, canola, and so on	Zero	<20%

Sources: Campbell (2005); Eckel *et al.* (2007); Health Canada (2006); Liu *et al.* (2002); Minihane and Harland (2007); Tarrago-Trani *et al.* (2006).

Table 9 Price of deep-frying oils in New Zealand

Oil	*Pack size*	*Price per pack (NZ\$/pk)*	*Price per volume (NZ\$/l)*
High-oleic sunflower	20 l	84.94	4.25
High-oleic sunflower/cottonseed	20 l	74.12	3.71
Cottonseed oil	20 l	60.27	3.01
Rice bran oil	20 l	58.99	2.95
Palm oil	20 l	33.68	1.68
Beef tallow	20 l	30.99	1.55

Source: Morley-John *et al.* (2002).
NZ$ = 0.78280 US$ (at December 2007).

proportion of the overall cost of the product; thus, the economic and nutritional cost/benefit of switching to trait-enhanced oils may be more acceptable to the industry. The largest cost in removing TFAs from most manufactured foods such as biscuits, cakes, crackers and chips is in recipe development, reformulation, relabelling and sensory evaluation of the foods. It seems economically sensible and farsighted that food producers use the occasion to choose a fat with zero *trans*, low in saturates and high in *cis*-unsaturates.

A recent survey in Iran illustrates the particular influence and importance that price may have on the supply, use and consumption of PHVOs in middle- or low-income countries. The results of the Food Consumption Survey of urban and rural households in Iran—7158 households, 35 924 individuals—showed that mean daily consumption of PHVOs was 14 g/1000 kcal (Mozaffarian *et al.*, 2007). Based on TFA analysis of PHVOs available in Iran and their market share, the mean intake of industrially produced TFAs in Iran was estimated at 12.3 g/day or 4.2% of energy. The authors of the report wrote, 'nearly all of the PHVOs used in Iran are imported and subsidized by the government for distribution as rationed oils', and point out the feasibility of reducing TFA intakes through governmental intervention. However, the actual cost for the government to replace PHVOs was not disclosed. The reader is referred to the case study of removing TFAs in India, which is covered elsewhere in this supplement (L'Abbé *et al.*, 2009).

World supply of unmodified vegetable oils and potential implications for supply of modified replacement fats

Information about the global supply and distribution of vegetable oils is readily available (United States Department of Agriculture, 2004; Ash and Dohlman, 2007) and is presented in Table 10. The world's consumption of vegetable oils in 2005–06 was estimated to have been 116 million metric tonnes, of which 60% was soybean and palm oil (Ash and Dohlman, 2007). It has been predicted that the world oil crop production will increase more than twofold from 104 to 217 million tonnes between 1999 and 2030, stimulated mainly by increased growth rates among developing countries, in particular from rising palm oil production in South Asia (FAO, 2003).

Information on the proportion of global vegetable oil supply that is converted to partially hydrogenated oils was difficult to obtain. Eckel *et al.* (2007) in their report on the American Heart Association *Trans* Fat Conference (2006) showed proprietary information from Dow AgroSciences that just over one-third of edible vegetable oils are converted to partially hydrogenated oils in North America (Table 11). Most experts state that the majority of PHVOs in the world are produced from soybean and canola oils (Tarrago-Trani *et al.*, 2006; Eckel *et al.*, 2007; Minihane and Harland, 2007).

Table 10 World consumption and supply of vegetable oils, 2005–06[a]

Oil	*World consumption*[b] *(metric tonnes × 10^6)*	*World supply*[b] *(metric tonnes × 10^6)*
Coconut	3.43 (3)	3.46 (3)
Cottonseed	4.56 (4)	4.55 (3.9)
Olive	2.78 (2.4)	2.59 (2.2)
Palm	35.24 (30.5)	35.96 (30.5)
Palm kernel	4.13 (3.6)	4.36 (3.7)
Peanut	5.19 (4.5)	5.16 (4.4)
Rapeseed (canola)	16.92 (14.6)	17.20 (14.6)
Soybean	33.70 (29)	34.30 (29)
Sunflower seed	9.70 (8.4)	10.40 (8.8)
Total	115.65 (100)	117.90 (100)

[a]Reproduced from Ash and Dohlman (2007).
[b]Values are in million metric tons (% total 2005–06).

Table 11 Consumption of unmodified and partially hydrogenated vegetable oils in North America[a]

Edible oil	*Amount*[b]	*% of total*[c]	*% Partially hydrogenated*	*Amount of PHVO*[b]
Soybean	8.08	70.3	41.7	3.37
Canola	1.18	10.3	26.7	0.32
Corn	0.78	6.8	36.1	0.28
Coconut	0.41	3.5	0	0.00
Cottonseed	0.32	2.7	17.7	0.06
Palm kernel	0.24	2.1	0.4	0.00
Palm	0.20	1.7	0	0.00
Sunflower	0.19	1.7	23.5	0.04
Peanut	0.11	0.9	11.6	0.01
Total	11.50	100	35.5	4.08

Abbreviation: PHVO, partially hydrogenated vegetable oil.
[a]Table reproduced from Eckel *et al.* (2007).
[b]Values are in million metric tons.
[c]Ash and Dohlman (2007).

Assuming that the proportion of each oil in the world's supply of partially hydrogenated oils is the same as in North America, approximately 22.8 billion metric tonnes or 19% of the world's vegetable oils are partially hydrogenated.

Removing PHVOs from the food supply requires replacement with fats and oils of similar physical and sensory properties. Tropical vegetable oils are, in most cases, the least expensive and easiest alternative oils, particularly palm oil; however, these oils are high in saturated fatty acids. With few exceptions, the view expressed by experts is that the removal of PHVOs from the food supply will tend to increase the use of palm oil. Of note, in this regard, is that palm oil imports into the United States during the 2005–06 marketing year soared by 72% from the previous year (Ash and Dohlman, 2007). In some countries where there is high availability and low cost of lard, tallow and butter, these may become, by default, the preferred replacement fats unless strategies are implemented to encourage manufacturers and foodservice industry to use high *cis*-unsaturated, low saturated substitutes.

Replacing TFAs from PHVOs with *cis*-unsaturated fatty acids can be achieved by using novel blends and trait-enhanced vegetable oils that are high in *cis*-monounsaturated fatty acids. Unfortunately, there is limited supply of these oils in the marketplace; many of them remain in the developmental stage. Proprietary supply information provided by five major seed and oil processing companies revealed that total supply in the United States of trait-enhanced high or mid oleic acid oils was 1.47 million metric tonnes (Eckel *et al.*, 2007). If this information is correct, the supply falls substantially short of the 4.08 million metric tonnes (Table 11) of PHVOs that should be replaced. Animal fats may fill some of the gap; however, the United States, which produces approximately 40% of the world's edible tallow and lard, had total supplies of tallow and lard of 0.8 and 0.4 million metric tonnes, respectively, in 2006 (Ash and Dohlman, 2007). If the world's supply of alternative fats and oils reflects that of the United States, then widespread international regulatory measures to prohibit or limit the use of PHVOs will require major coordination with the food industry to increase the availability of nontropical vegetable alternatives to avoid a dramatic increase in saturated fat intake. In the event that regulations are introduced simultaneously to prohibit the use of TFA-containing fats and oils, the immediate demand for substitute oils has the potential to overwhelm the supply of trait-enhanced fats and oils high in *cis*-unsaturated fatty acids. This may be one of the reasons for the 72% increase in palm oil imports into the United States between 2004–05 and 2005–06; notwithstanding, palm oil and palm kernel oil comprise less than 4% of the consumption of oils in North America (Table 11).

Examples of regulatory approaches to reduce population intakes of *trans*-fatty acids

There are several approaches that have been initiated by governmental and public health organizations in different countries to reduce TFA intake. These include nutrition recommendations about TFAs, raising awareness about adverse effects of TFAs through nutrition and health claims, voluntary or mandatory labelling of TFA content of foods, voluntary reformulation by industry and mandatory regulation of food standards. The initiatives underway in a range of countries are shown in Table 12.

A summary of available international and national recommendations (Nijman *et al.*, 2007) revealed that only nine out of 19 countries had nutrition recommendations to limit TFA intake; six of the nine countries with recommendations advocated that TFA intake in individual diets should not exceed 1% of total energy.

Adopting a regulation to prohibit the use of PHVOs in foods—as occurred in Denmark—will lower population intakes of TFAs independent of the monitoring of intakes. Compliance with the regulation is the main factor that will determine its effectiveness to reduce TFA intake. Denmark's food regulations (Foodstuffs Act) prohibit the food industry from using oils and fats that contain more than 2 g of (industrially produced) TFAs per 100 g of oil or fat. The regulation has been in force since 1 June 2003.

Regulations that require nutrition information panels to show the TFA content of foods—as adopted in the US—will only be effective at reducing TFA intakes in the population, if consumers read the food labels and avoid foods with TFAs or if the food industry reformulates their products using TFA-free oils. It is taken that a regulatory approach based on a nutrition information panel is relevant only in those countries where literacy rates are high. The extent to which food manufacturers and foodservice establishments remove TFAs from their products will be driven by consumer demand for products with low amounts of TFAs. The ability to monitor population intakes through nutrition surveys, although useful, is not the determinant of industry change. The major limitation of the regulatory approach in the United States is that it excludes foods that do not carry a nutrition information panel, such as foods prepared in foodservice establishments; thus, the regulatory action by the New York City Board of Health to ban TFAs from restaurant foods is of relevance. Furthermore, relying on mandatory nutrition labelling to reduce TFAs in the food supply—as is the case in the United States—has a potential drawback in that by focusing attention on the TF content of foods, consumers may overlook the saturated fat content and choose foods that are lower in TF yet substantially higher in the combined total of *trans* plus saturated fat. Because of this concern, nutrition labelling regulations in Canada require declaration of the quantity of both saturated and TF on separate lines, as well as a single per cent daily value for the total of saturated fatty acids and TFAs. The regulatory approach, as adopted in Denmark, to prohibit the food industry from using fats and oils with TFA content greater than 2% of fat removes TFAs from the food supply, without having to add TF labelling to the nutrition information panel. This approach does not overcome the problem that food manufacturers may switch to fats high in saturated fat, but it may avoid consumer confusion when reading the *trans* and saturated fat information on food labels.

The need for concurrent strategies to encourage the use of high *cis*-unsaturated replacement fats

Government initiatives to encourage food manufacturers and the foodservice industry to use *cis*-unsaturated fats instead of TFAs extend little beyond the level of recommendations and food guidelines for the general population. The TFA initiatives tend to regulate or discourage the use of PHVOs, whereas the choice of substitute fats and oils is left to market forces. The opinion commonly expressed in the

Table 12 Summary of voluntary and mandatory regulations to reduce *trans*-fatty acids in the food supply

Country	*Measure*	*Outcome*
Denmark (Leth *et al.*, 2006)	2003: Voluntary labelling and/or health claims. No mandatory declaration of TFA. Mandatory compositional restrictions of TFAs in fats and oils to <2% of total fatty acids	Phased-in implementation from June 2003 to January 2004
United States (Eckel *et al.*, 2007; Food and Drug Administration, 2003; Okie, 2007)	2006: Mandatory labelling of TFA content in foods containing levels of 0.5 g or more per serving and when claims are made concerning fat, fatty acids or cholesterol. Includes both manufactured and ruminant sources	Increased public awareness, product reformulation. New York-based AC-Nielsen survey reported that US sales of 'no *trans* fat' labelled products increased by 12% between 2003 and 2004
	2005: USDA and Department of Health and Human Services issue guidelines recommending reducing TFA consumption and requesting food industry to decrease *trans* fat content	
	2006: New York City Board of Health announces *trans*-fat ban in restaurants	2007: TFA content limited to less than 0.5 g in most foods in New York City restaurants
	2008: New York City: Baked goods and products containing deep-fried batter may not contain more than 0.5 g of *trans* fat	
Canada (Health Canada, 2006)	2003: Voluntary labelling	Heightened consumer awareness
	2005: Mandatory labelling. Regulatory action by Food and Drug Regulations (FDR) requires declaration of TFA content in grams per serving. A declaration of 'zero grams' of *trans* fat may be made on the label if the *trans* fat content is less than 0.2 g per serving and contains less than 2 g of saturated fat ('low' in saturated fat)	Almost all bread and salad dressings are TFA free. Many other foods still contain high amounts of TFA (2005)
	2006: The Trans Fat Task Force recommends regulatory TFAs to less than 2% of total fat in fats, oils and margarine, and less than 5% of total fat in manufactured foods. Includes retail, food service or food prepared on site	Covered elsewhere in this supplement
	2007: Minister of Health announced that Health Canada is adopting the Trans Fat Task Force's recommended limits for *trans* fats in Canadian foods and giving industry 2 years to reduce *trans* fats to the levels recommended by the Trans Fat Task Force. If significant progress has not been made over the next 2 years, commits to regulate to ensure the levels are met. Also commits to publish results of Health Canada monitoring program	
Australia/New Zealand (Food Standards Australia New Zealand, 2007)	Voluntary labelling of TFA content and/or health claims, mandatory if nutrient content claims made for fatty acid or cholesterol content. Recent review recommends nonregulatory approach to reduce TFA because intake of industrially produced TFAs is probably low	

scientific literature is that unless initiatives to reduce the use of industrially produced TFAs coincide with specific measures to encourage the use of substitute oils free of TF and high in *cis*-unsaturated fatty acids, a large section of the food industry may replace PHVOs with fats and oils high in saturated fat. In some high-fat foods where the TFA content of PHVOs is very high (that is >40% of total fatty acids), there may be 'health gains' by using tropical or animal fats as substitutes; however, these gains are small in comparison with zero *trans*, low saturated, high *cis*-unsaturated replacement fats. This topic is discussed in detail by Mozaffarian *et al.* (2009) elsewhere in this supplement. The most common examples of oils high in saturated fats are palm, palm kernel and coconut oil as well as animal fats such as lard, tallow and butter. Other alternatives suggested by industry include the use of reduced *trans* hydrogenation processes and the use of interesterified blends containing hard fats (tristearin), obtained synthetically by the full hydrogenation of liquid oils resulting in fats high in stearic acid with a TFA content between 1 and 2% of total fat.

However, there are examples of voluntary food labelling leading to product reformulation to lower *trans* and saturated fatty acids and increase *cis*-unsaturated fats. The 'Pick the Tick' programme of the Heart Foundations in Australia and New Zealand allows food manufacturers to purchase a front-of-pack 'Tick' logo to indicate that the food is a healthier food choice compared with foods in the same food category. To carry the logo, the salt, fat, saturated fat and sodium must be lower than a specified target; for the relevant foods, fibre content must exceed minimum targets. The TF target for all foods is 'zero *trans*'; in the case of margarines and oils, this is less than 1% of total fat. The

Heart Foundation of Australia is implementing a particularly novel, and somewhat controversial, approach by expanding the 'Pick the Tick' programme to include foods prepared in restaurants, fast-food outlets and the foodservice industry (Heart Foundation of Australia, 2007). Food establishments—for example McDonald's, Burger King or Pizza Hut—can label their foods with a 'Heart Tick' if it meets stringent criteria for TF, saturated fat, sodium and energy content. One of their earliest guides is a three-step approach to reducing *trans* and saturated fatty acids in the Australian foodservice industry. The guide includes a price list and application description of suitable alternative vegetable oils for deep-frying and pan-frying. In the United States, it appears that the American Heart Association's approach is primarily to educate consumers and health professionals to recognize and avoid *trans* and saturated fats, the 'Bad Fats Brothers'.

Arguably, the most successful industry-led initiative has taken place in the Netherlands. Katan (2006) describes how Unilever decided in the early 1990s, in response to scientific evidence of the adverse effects of TFAs on blood cholesterol concentrations, to remove TFAs from spreads and other foods without increasing their saturated fat content. The development of margarine and table spreads with virtually no TFAs contributed to a reduction in TFA intake between 1985 and 1996 of 2 g/day. Katan (2006) also describes how in 2004, the Product Board for Margarine, Fats and Oils in the Netherlands initiated a campaign to reduce the use of PHVOs in fast foods and baked goods. The major fast-food chains acted almost immediately to remove TFAs and did so by increasing *cis*-unsaturates and not saturates. Independent outlets were slower to respond, with 45% of them using frying oils with less than 5% TFAs and more than 55% *cis*-unsaturates by 2005.

The development of TFA-free table spreads and their distribution worldwide had a major impact on TFA intakes in some countries, notably, in Australia and New Zealand, where *trans*-containing vegetable oil table spreads accounted for the vast majority of industrially produced TFAs in the food supply prior to the rapid introduction of 'zero-*trans*' spreads in mid-1996 (Lake, 1995). Recent dietary modelling work suggests that intake of TFAs from hydrogenated sources is now around 0.15 and 0.3% of total energy in Australia and New Zealand, respectively (Food Standards Australia New Zealand, 2007).

Monitoring compliance

The lack of TFA data in food composition databases is undoubtedly a major obstacle in most countries for monitoring the extent to which industry and government initiatives succeed in reducing TFA intake; however, it is not by itself an obstacle for implementing those initiatives or for those initiatives to be effective.

Monitoring compliance will depend on the nature of the regulatory or nonregulatory approaches adopted to eliminate or reduce population and individual intakes of industrially produced TFAs. Given that the greatest benefit to population health will depend not only on the removal of TFAs from the food supply but also on their replacement with *cis*-unsaturated fats rather than saturated fatty acids from animal fats or tropical oils, it is important that monitoring is able to detect changes in all types of fatty acids. Methods of monitoring can include the supply and distribution of fats and oils, fatty acid analysis of foods, dietary assessment and measurement of biological markers.

In countries that follow the example of Denmark and prohibit the use of fats and oils that exceed a fixed proportion of TFAs, the simplest and most effective monitoring approach is to systematically sample manufactured foods and foods prepared by the foodservice industry and to measure their fatty acid composition. This will not only track compliance with the TFA regulations, but it will also provide information about the composition of the fats and oils that are replacing PHVOs. There is reasonable argument that dietary intakes of TFAs do not need to be assessed because exposure is controlled by supply.

A paper presented at the First International Symposium on the Health Effects of *Trans* Fatty Acids in Denmark in 2005 by Leth *et al*. (2006) explained how the TFA compositions of 148 food samples collected in 2005 were compared with similar products that had been collected in 2003. The authors wrote, 'much fewer of the samples than in the earlier investigation contained more than 2% TFAs of the fat and most of them with between 2 and 6% TFAs, some even with milk ingredients'. Analysis of the TFA content of French fries and chicken nuggets purchased between November 2004 and September 2005 from Danish Kentucky Fried Chicken and McDonald's restaurants showed a fat composition of 1% TFAs (Stender *et al*., 2006a). These results, although not a comprehensive survey of the food supply or dietary intakes of the population, suggest that food manufacturers and foodservice establishments are complying with the regulations. Importantly, they do not reveal the fatty acid composition of the substitute fats and oils.

Where food labelling of TFAs or other fatty acids is not required, it may be useful to include the name of the oil in the ingredient list rather than a generic term such as 'vegetable oil'. The naming of the type of oil in the ingredient list can be used to confirm the fatty acid analysis of the food. However, manufacturers tend to resist naming the ingredient oils because the type of oil in a food product is often changed according to availability and price; the generic term 'vegetable oil' does not require relabelling.

In countries where reducing TFA intakes rely on mandatory food labelling of TFAs, a dietary assessment approach becomes more important. Given that manufacturers are required to employ accurate methods to analyse the TFA composition of their food products, it may be possible to develop systems to link manufacturer's data with food composition databases. The obvious deficiency of this system is that the food label does not contain information on the amount of *cis*-monounsaturates and *cis*-polyunsaturates in the food. Therefore, monitoring intakes will require independent analyses of the fatty acid composition of foods.

Biomarkers of TFA intakes can be a reasonable alternative to dietary assessment. Biological markers of fat intake offer an alternative to assessing TFA exposure because tissue fatty acid composition reflects actual rather than reported intake, thus avoiding the particular problems of quantifying 'hidden' fats or the well-established underreporting of fat intake (Beaton *et al.*, 1979; Bingham, 1987; Bingham *et al.*, 1994). Biomarkers of TFA intake are particularly good (Vidgren *et al.*, 1998; Lichtenstein *et al.*, 2003) because there is negligible endogenous synthesis of TFAs and there is a dose–response relation with dietary intake (Mensink and Hornstra, 1995). There are examples of biomarkers being used to monitor changes in population intakes of TFAs over time (Innis *et al.*, 1999; Clifton *et al.*, 2004; Colon-Ramos *et al.*, 2006). Biomarkers are also very sensitive to changes in saturated and polyunsaturated fatty acid intakes (Zock *et al.*, 1997; Smedman *et al.*, 1999; Skeaff *et al.*, 2006); therefore, concurrent changes in the saturated and polyunsaturated fatty acid intakes that accompany removal of PHVOs from the food supply will be captured. *Trans*-fatty acid labelling of foods became mandatory in Canada in December 2005. Friesen and Innis (2006) used the relation between breast milk and dietary TFAs to predict that TFA intake of women in their study decreased from 3.4 to 2.7 to 2.2 g/day during the corresponding periods. Results from the Canadian study suggest that mandatory labelling had an immediate effect on the amount of TFAs in the food supply. Furthermore, Clifton *et al.* (2004) showed in a study conducted in Adelaide that the per cent of TFAs in adipose tissue was significantly higher in participants biopsied before in comparison with that after mid-1996, a date that corresponds with the removal of most spreadable fats with TFAs from the food supply.

Cost of monitoring includes random food sampling and analyses of the foods. For biomarker studies, it involves recruitment of participants, collection of biological samples and analyses of fatty acid composition. There are two methods of TFA analysis described by the Food and Drug Administration as suitable for declaring the TFA content of foods: gas chromatography (Association for Official Analytical Chemists method 996.06) and attenuated total reflection–Fourier transform infrared spectroscopy (American Oil Chemists Society Cd 14d-96). The infrared method measures only TFAs, whereas the gas chromatography method measures all fatty acids. Therefore, the gas chromatography method is preferred for the purposes of monitoring compliance because it provides information not only on the elimination of TFAs but also on the replacement fatty acids. The Food and Drug Administration stated in their final ruling that the cost of analysing each food sample was approximately US$300.

Conclusions

The use of PHVOs-containing TFAs is widespread in the global food supply as ingredients in manufactured foods and foods prepared in the food service industry. The Joint WHO/FAO Expert Consultation on Diet, Nutrition and the Prevention of Chronic Diseases recommended that population intakes of industrially produced TFAs should not exceed 1% of total dietary energy. Population estimates of TFA intake are difficult to make with precision and accuracy; however, the evidence suggests that most countries probably have mean intakes of TFAs that exceed the recommendation, in some cases by several units of per cent energy. Although there is limited information about the distribution of TFA intakes in most countries, it is likely that many subgroups within the population, particularly those who consume a high proportion of manufactured or restaurant foods, have mean TFA intakes considerably higher than the population mean.

Removing industrially produced TFAs requires the replacement of PHVOs with alternative fats, preferably vegetable oils high in *cis*-unsaturated fats rather than tropical oils and animal fats, which are high in saturated fat. However, in the case of PHVOs with very high TFA content, replacement with high saturated fat oils may convey some, albeit limited, benefit. It is widely held that the easiest substitution is to use tropical oils such as palm, palm kernel or coconut oils. Supply of these oils is abundant, price is low, the food industry has used them for long, and their physical and sensory properties produce foods with favourable characteristics.

Substitute vegetable oils low with zero or low TFAs and high *cis*-unsaturates can replace PHVOs and maintain food product quality. However, it appears that limited supply of these substitute oils will be a hindrance to their use. It has been estimated that 4.08 million metric tonnes of PHVOs was consumed in North America in 2005–06; however, the supply of suitable high *cis*-unsaturated trait-enhanced or novel vegetable oils was 1.47 million metric tonnes. This leaves a substantial deficit, which may be filled by tropical oils or animal fats. International efforts by the food industry to reduce use of PHVOs will need to coordinate with supplies of appropriate alternative oils to avoid the decrease in TFA intake being accompanied by a larger increase in saturated fatty acids, which would not exploit the entire health potential in reformulation of the manufactured foods containing TFAs.

Current knowledge about TFA intakes in different countries is not robust having been gained through pragmatic dietary assessment methods that did not rely on food composition databases with complete TFA data. The effort to monitor the impact of regulatory and nonregulatory initiatives on TFA intakes should be commensurate with the degree of effort their introduction has required. During the transition phase of implementing governmental and industry-led initiatives, few countries will have the resources to develop food composition databases with complete TFA data or update existing databases. Monitoring, therefore, should consist of systematic sampling and analysis of foods likely to contain PHVOs and analysis of the saturated fat content of reformulated foods once TFs have been removed. Furthermore, biomarkers should be used to assess TFA exposures in representative samples of the population. Monitoring is not only for the purpose of assessing changes in TFA intakes but also for assessing the fatty acids that replace them.

Conflict of interest

During the preparation and peer-review of this paper in 2007, the author and peer-reviewers declared the following interests.

Author

Dr Murray Skeaff: Led a research project that tested the effects of a plant sterol-enriched fat spread on blood cholesterol concentrations; costs of the research partially funded by Unilever Research and Development (2003–2004); participated in a subcontract to conduct a randomized controlled trial of a milk product enriched with an antioxidant extract from vegetables, which was partially funded by Fonterra, a milk company in New Zealand (2005–07). All industry-supported research projects were organized and administered through the University of Otago Research and Enterprise Unit.

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