Taking *Trans* Fats Out of the Food Supply

Terrence Madhujith and Subajiny Sivakanthan

1 Introduction

Lipids are a group of chemically diverse compounds which are soluble in organic solvents and insoluble in water (Fahy et al. 2011). Food lipids are classified based on their physical state at ambient temperature. Food lipids in solid forms are termed fats, while liquid forms are named oils. Food lipids also can be classified based on their polarity as nonpolar lipids (e.g. triacylglycerols and cholesterol) and polar lipids (e.g. phosphoacylglycerols) indicating the differences in their solubility and functional properties. Foods vary in their quantity and the composition of lipids (Damodaran and Parkin 2017).

Lipids are made up of fatty acids and glycerol. Fatty acids are carboxylic acids carrying mostly an even number of carbon atoms in aliphatic chain, a carboxylic acid, and a methyl group at two ends (Fig. 1). Fatty acids with odd number of carbon atoms can be found in minute quantities in some microorganisms and dairy fats. Aliphatic chain of the fatty acids may contain double bonds; thus, fatty acids are classified as saturated and unsaturated (monounsaturated and polyunsaturated) (Lannes and Ignácio 2013; Chatgilialoglu et al. 2014). Majority of the naturally occurring unsaturated fatty acids occur in *cis* forms (Valenzuela and Valenzuela 2013). Most dietary *trans* fats are generated by the partial hydrogenation of unsaturated vegetable oils. Partial hydrogenation is carried out in order to increase the oxidative stability and thereby to extend the shelf life and to enhance the physicochemical properties of foods. The lipids modified through partial hydrogenation can potentially replace animal fats such as lard, tallow, and butter (Puligundla et al. 2012;

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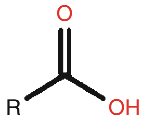

Fig. 1 Structure of fatty acid (R denotes aliphatic chain)

Lannes and Ignácio 2013). Epidemiological studies have reported that there is a strong positive correlation between the intake of industrially produced *trans* fatty acids and cardiovascular diseases (de Souza et al. 2015). However, the conjugated linoleic acid (CLA), a type of *trans* fats with conjugated double bonds naturally present in the ruminant meat and milk, is known to possess a myriad of health benefits (Wannamethee et al. 2018).

As a result of scientific findings indicating the adverse health effects, *trans* fat becomes one of the centers of focus in the food industry. Several high-income countries commenced restricting *trans* fat contents of foods; however, low- and middle-income countries failed to mitigate *trans* fats in their food supplies. Studies on *trans* fat consumption in Sri Lanka is lacking; however, it is suspected that a considerable number of food items commonly consumed in the country contain high levels of *trans* fat. Therefore, there is a timely need to urge the regulatory authorities to take necessary actions to mitigate the *trans* fat levels in the Sri Lankan diet. In this backdrop, this chapter reviews the chemistry and health effects of *trans* fats, global scenario on regulations on *trans* fat levels, and the possible measures to mitigate *trans* fats in Sri Lankan food supply.

2 Chemistry of *Trans*-Fatty Acids

Trans-fatty acids are unsaturated fatty acids with at least one ethylenic double bond in the *trans* geometrical configuration. However, for labelling purposes, restricted definitions have been proposed for *trans* fats which exclude fatty acids containing conjugated double bonds which are known to possess health benefits (Ledoux et al. 2007; Silva et al. 2014). Fatty acids with c*is* configuration carry the hydrogen atoms on the same sides of the molecule providing a "V" shape, and this is considered the usual form of fatty acids naturally found in foods. On the other hand, the fatty acids with *trans* configuration bearing the hydrogen atoms on the opposite sides of the molecule leading to a near linear configuration (Fig. 2) (Żbikowska 2010), are more rigid and straight molecules with a higher melting point than their *cis* counterparts (Remig et al. 2010).

3 Classification of *Trans* Fats

Trans fatty acids can be classified as naturally occurring and industrially produced (artificial). *Trans* fatty acids are produced by the gut flora of ruminant animals via the process known as biohydrogenation; thus, *trans* fatty acids occur naturally in minute quantities in meat and milk derived from ruminants such as cattle, sheep, and goats.

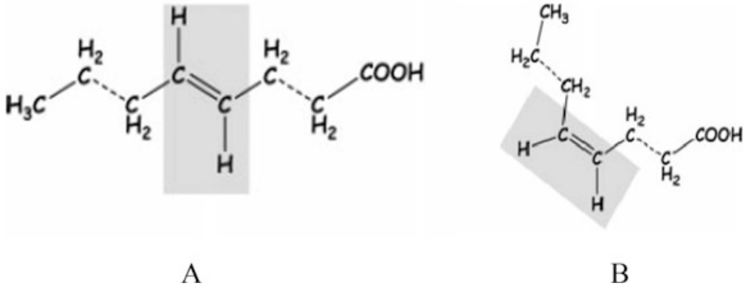

Fig. 2 Configuration of *trans*-fatty acid (**a**) and configuration of *cis* fatty acid (**b**)

However, the origin of most of the *trans* fats in the human diet is not ruminant products. The main sources of *trans* fatty acids are partially hydrogenated vegetable oils, margarines, shortenings, other fat spreads produced through partial hydrogenation, baked goods, and frying fats and fried products. In addition, refining of edible oils, frying, and food irradiation also lead to formation of considerable amounts of *trans* fats in foods (Martin et al. 2007).

3.1 Natural *Trans* Fats

3.1.1 The Origin

The microflora found in rumen of ruminants carry isomerases, which isomerize naturally existing form of fatty acids (*cis*) into *trans* form. Biohydrogenation of 18-carbon polyunsaturated fatty acids such as linoleic acid forms primarily vaccenic acid (11-*trans*-octadecenoic acid) and conjugated linoleic acid (CLA) (9-*trans*, 11-*cis*-octadecadienoic acid). *Trans*-fatty acids generated in the rumen of ruminants are transported to milk and muscles where they are deposited in fat (Żbikowska 2010; Remig et al. 2010). As these *trans* fats occur naturally, it is impossible to eliminate *trans* fats completely from these sources. However, the amount of *trans* fats arising from the ruminants is less likely to cause adverse health effects (Uauy et al. 2009; Downs et al. 2013b). In fact, to the contrary, CLA is known to provide a myriad of health benefits (Silva et al. 2014); thus, it is encouraged to have CLA in the diet (Fig. 3).

3.1.2 Health Benefits of Natural *Trans* Fats

Even though there are sufficient evidences to suggest the adverse health effects of *trans* fats, recently, a paradox arises that the natural *trans* fats produced by ruminants such as vaccenic acid and CLA do not harm the human health. In the past decade, CLA gained much attention due to their potential health benefits (Wannamethee et al. 2018). It is proven that CLA possesses therapeutic potential such as antiatherogenic, antidiabetic, anti-inflammatory, and anti-oncogenic effects and immune-modulating properties (Silva et al. 2014; Wannamethee et al. 2018). Thus, the definition of *trans* fat in the Codex Alimentarius standard, as well as

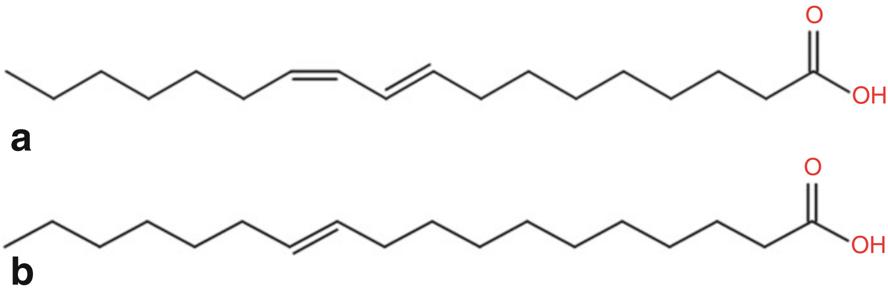

Fig. 3 Structure of conjugated linoleic acid (9-*trans*, 11-*cis*-octadecadienoic acid) (**a**) and vaccenic acid (11-*trans*-octadecenoic acid) (**b**)

definition by some other countries such as the United States, Canada, and Denmark, has been amended to exclude *trans* fatty acids containing conjugated double bonds for labelling purposes (Gebauer et al. 2011).

Both human and animal studies have suggested that CLA possesses cardiovascular health benefits (Wannamethee et al. 2018). Recent research on humans suggested that CLA would act to reduce adiposity via modulation of lipid metabolism (Lehnen et al. 2015). The possible mechanisms of action of CLA to alter the body composition involve metabolic changes favoring the reduction of the lipogenesis and the potentiation of lipolysis, together with the increased oxidation of fatty acid in the skeletal muscles because of increased carnitine palmitoyltransferase-1 activity (Churruca et al. 2009). A study on Wistar rats to supplement CLA at a rate of 2.0% and 4.0% with respect to the daily feed intake reported 18% reduction in body fat (Botelho et al. 2005). A recent study has reported an inverse association between serum CLA level and risk of heart failure in older men (Wannamethee et al. 2018). The anticarcinogenic properties of CLA have been studied experimentally. It has been reported that animal studies show a beneficial effect of CLA in mammary cancer (Gebauer et al. 2011).

3.2 Formation of Industrial *Trans* Fats

3.2.1 Partial Hydrogenation of Oils

Hydrogenation is a process of adding hydrogen to the double bonds of unsaturated fatty acids in the presence of catalyst, in general nickel. The intermediate product with only one hydrogen added does not contain double bond, thus rotating freely. Thus, the double bond can re-form as either *cis* or *trans*, of which *trans* is energetically more stable. During complete hydrogenation, all unsaturated fatty acids get saturated leading to hard fat; thus, it does not lead to generation of *trans* fatty acids. As a result, *trans* fat is produced as a by-product of partial hydrogenation only. Partial hydrogenation affects mostly the 18:1 isomers while reducing the amount of polyunsaturated fatty acids (PUFA) in the original oil (Ledoux et al. 2007). Elaidic acid (*trans*-9-octadecenoic acid) and linolelaidic acid (*trans*-9,12-octadecadienoic

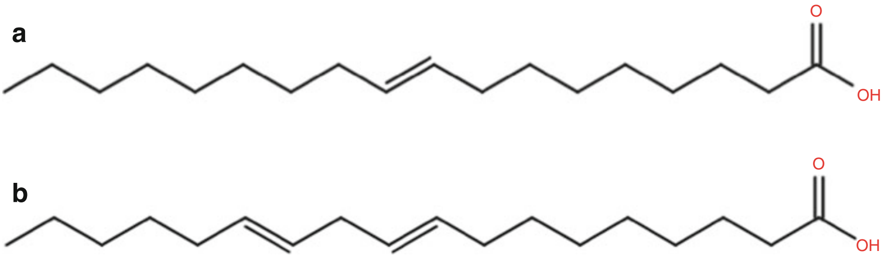

Fig. 4 Structure of elaidic acid (*trans*-9-octadecenoic acid) (**a**) and linolelaidic acid (*trans*- 9,12-octadecadienoic acid) (**b**)

acid) are the major *trans* fatty acids produced during partial hydrogenation, which are estimated to be found in partially hydrogenated vegetable oils at 85–95 and 8–22%, respectively (Żbikowska 2010) (Fig. 4).

During the partial hydrogenation process, oil is hardened, which, when used in food products, enhances its texture and other sensory qualities and increases the shelf life and tolerance to repeated heating. The proportions of industrially produced *trans* fats are usually much higher in processed foods than in natural foods (WHO 2015).

Partially hydrogenated fats may contain up to 50% of *trans* isomers (Guillén and Cabo 1997). Amount of *trans* fat depends on PUFA composition of the native oil, type and amount of the catalyst used in the hydrogenation process, final hardness, and other hydrogenation conditions such as temperature, length of treatment, pressure, and stirring intensity (Ledoux et al. 2007). Thermal treatments of fats and oils carried out during processing of edible oils such as deodorization and cooking and frying operations during preparation of food generate *trans* fats with limited number of double bonds leading to the formation of mainly *trans*-18:2 and *trans*-18:3 (Żbikowska 2010).

3.2.2 Oil Refining

Crude vegetable oils contain non-triacylglycerol compounds which contribute to undesirable physicochemical properties, thus reducing the acceptability and limiting the shelf life. Therefore, oils are refined to remove these unacceptable substances. Refining process includes the steps such as degumming, neutralization, bleaching, and deodorization. During deodorization, oil is heated to 180–270 °C which can result in the formation of *trans* fats. The quantity of *trans* fats formed depends on the temperature and duration of the process (Martin et al. 2007). Thus, refined oils with high level of unsaturation such as sunflower oil may contain *trans* fats.

3.2.3 Frying and Other Culinary Operations

Fried foods are preferred by consumers all over the world due to their unique sensory qualities such as crispy texture, aroma, and golden brown color. However, during the frying process, *trans* fats are generated especially when unsaturated oil is used for frying. Frying foods using oils containing polyunsaturated fatty acids at temperatures above 180 °C for prolonged period of time generates *trans* fats. The extent of formation of *trans* fats during frying depends on the temperature and duration of frying (Martin et al. 2007). Several European countries have determined that the frying temperature should not exceed 180 °C. The ideal frying oil should contain the lowest possible linolenic acid content (less than 2%). In France, it has been established that the commercial frying oil should contain less than 3% α-linolenic acid (Martin et al. 2007). When partially hydrogenated oils are used as frying oils, the formation of *trans* fats is generally low; however, the high initial amount of *trans* fats will result in high amount of *trans* fats in fried food (Martin et al. 2007). A study carried out in the central province of Sri Lanka revealed that over 90% of snack producers use palm oil for frying, and some snack makers use the same oil nearly 40 times during the day (Jayawardena et al. 2014).

3.2.4 Food Irradiation

Irradiation is a promising novel technique used in food preservation. Ionizing radiation causes destruction of pathogenic microorganisms as well as spoilage microorganisms by permanently damaging the DNA (Ganguly et al. 2012). Irradiation of lipids induces the production of free radicals, which react with oxygen, leading to the formation of carbonyls (Brito et al. 2002). Breaking the double bond of unsaturated fatty acids during food irradiation favors the formation of *trans* fatty acids (Martin et al. 2007). Even though, in food preservation, the use of irradiation technology has gained much interest in some countries, it is not so far used in Sri Lanka. Therefore, the *trans* fats produced by the irradiation do not have significant contribution.

4 Sources of Industrially Generated *Trans* Fats

Trans isomers are not found in natural vegetable oils. Partially hydrogenated oils and fats are used for the production of hardened margarine spreads, and these are used for the production of sweet snacks (cookies, cake, doughnuts, pie, crackers and other baked products, and chocolates), salted snacks (French fried potatoes and chips), instant soups, pizzas, and takeaway foods. Thus, these foods are likely to contain significant levels of *trans* fats. In several countries, partial hydrogenation has been replaced by alternative technologies. In Sri Lanka, some food manufacturers, restaurants, and bakers use shortenings made out of partially hydrogenated oils as they are less expensive.

5 Health Concerns of *Trans* Fats

There are evidences to show that consumption of *trans* fat is well associated with the development of cardiovascular diseases (Nestel 2014). Furthermore, *trans* fat intake is also associated with the development of diabetes, dementia, cancer, and infertility and affects fetus. The US-FDA has announced that *trans* fats are not generally recognized as safe (GRAS) for any use in food (Ryan 2014).

Trans fatty acids are present in the diet in esterified form, mainly in triacylglycerols; however, those from ruminant sources may also be present in phospholipids. Before absorption into the body, triacylglycerols must be digested by pancreatic lipase in the small intestine. The hydrolysis and absorption of *trans* fatty acids are similar to that of *cis* fatty acids. Dietary *trans* isomers are incorporated into membranes and other cellular structures. Dietary *trans* fatty acids are incorporated into the brain, liver, adipose tissue, spleen, blood plasma, and milk. *Trans* fatty acids are transported across the placenta and secreted in human milk, and the levels depend on the maternal dietary intake of *trans* fat (Larqué et al. 2001; Sadler 2005; Innis 2006; Żbikowska 2010).

5.1 Cardiovascular Diseases

Cardiovascular diseases remain the principal cause of mortality worldwide (Zapolska et al. 2015). There is strong evidence to support the link between the consumption of *trans* fats and the risk of developing cardiovascular diseases (Chowdhury et al. 2014). The World Health Organization (WHO) points out that *trans* fats increase the risk of cardiovascular diseases more than any other dietary source of energy. *Trans* fats contribute to cardiovascular diseases via multiple risk factors such as increasing plasma concentrations of lipids and lipoproteins and inflammatory markers, impairing endothelial function and possible effects on coagulation, insulin resistance, and displacement of essential fatty acids from membranes, affecting prostanoid-related functions and possibly other key membrane-related functions (Uauy et al. 2009; Gebauer et al. 2011; Takeuchi and Sugano 2017).

Trans fatty acids induce the development of a pro-atherogenic lipid profile leading to increased cardiovascular risk (Revoredo et al. 2017). *Trans* fats mediate the increased risk of cardiovascular diseases by increasing low density cholesterol (LDL-C) levels, total cholesterol, and triacylglycerols and decreasing the levels of high-density lipoprotein cholesterol (HDL-C) in plasma. *Trans* fatty acids create more space for the transport of cholesterol by gathering together inside LDL-C particles. Further, *trans* fats can reduce gene expression of hepatic receptors responsible for the uptake of LDL-C (Hunter et al. 2010; Revoredo et al. 2017). The LDL fraction may be deposited in blood vessels and lead to arteriosclerosis (Remig et al. 2010; Żbikowska 2010; Bendsen et al. 2011a). Thus, *trans* fats increase the LDL/HDL ratio, total cholesterol/HDL apolipoprotein A/apolipoprotein B ratio, and cholesterol content both in LDL and HDL particles in comparison to saturated fatty acids. Moreover, *trans* fatty acids increase hepatic secretion of very low-density lipoprotein (VLDL) and their particle size (Dashti et al. 2002; Chowdhury et al. 2014). Cardiovascular disease is described as an inflammatory disease. C-reactive protein is considered as a better predictor of future cardiovascular incidences than lipid and lipoprotein levels alone. The *trans* fats have been shown to increase inflammatory markers, including C-reactive protein, interleukin-6, and tumor necrosis factor-α, possibly through modulation of monocyte and macrophage activity (Ridker et al. 2002; Remig et al. 2010).

The WHO and the Food and Agriculture Organization (FAO) of the United Nations recommend that daily energy intake from *trans* fats should be less than 1% of total energy intake which is equal to no more than 2 g of *trans* fats per day for a person requiring 2000 kcal (WHO 2003). It is estimated that 2% increase of total energy derived from *trans* fat is associated with an increase in risk of deaths by heart diseases by 23% (Mozaffarian et al. 2003). Moreover, it has been proven that with replacement of partially hydrogenated vegetable oils with alternative fats and oils, the risk of coronary heart diseases may be reduced by as much as 50% (Mozaffarian and Clarke 2009). Removing *trans* fats from the food supply is perhaps one of the most straight forward public health interventions for reducing cardiovascular disease risk (WHO 2015). The US-FDA has estimated that labelling regulations on *trans* fat levels could save up to 500 lives per annum in the United States by reducing the incidence of cardiovascular disease (Resnik 2010). In Denmark, over a period of 20 years, the number of deaths due to coronary heart diseases has been reduced by nearly 50% by the regulations on *trans* fat levels (Iqbal 2014).

5.2 Effects on Early Human Development

Even though earlier studies concluded that human placenta can act as a barrier for *trans* fatty acids, subsequent studies found that *trans*-fatty acid levels in cord blood of term infants are similar to the levels in maternal plasma lipids (Larqué et al. 2001). Dietary *trans* fatty acids are transported to the fetus via placenta and incorporate into fetal tissues, which may lead to infantile birth weight in preterm and healthy term babies as well as reduce the duration of pregnancy (Żbikowska 2010). It has been reported that *trans* fat levels are inversely correlated with infantile birth weight in preterm and healthy term infants (Larqué et al. 2001).

5.3 Diabetes Mellitus

Studies have revealed that *trans* fats may contribute to development of diabetes mellitus. Fourteen-year observation of Nurses' Health Study revealed that the risk of developing type 2 diabetes is associated with *trans* fatty acid intake (Salmeron et al. 2001). Both saturated and *trans* fatty acids increase the risk of developing diabetes; however, the effects of *trans* fatty acids are greater than those of saturated fatty acids (Dhaka et al. 2011). *Trans* fatty acids influence peripheral insulin sensitivity and the risk of developing type 2 diabetes by affecting cell membrane functions (Risérus et al. 2009). *Trans* fat may increase hepatic lipogenesis leading to a greater intolerance to glucose and also induce a reduction in the synthesis of Acylation Stimulating Proteins (ASP) which could contribute to peripheral resistance to the insulin action (Bendsen et al. 2011b; Revoredo et al. 2017).

Studies suggest that there is a differential effect of *trans* fatty acids compared with *cis* fatty acids on the regulation of insulin secretion, with *trans* fatty acids potentiating glucose-stimulated insulin secretion more than *cis* isomers of identical chain length (Thompson et al. 2011). Risérus suggested that replacing *trans* fatty acids with monounsaturated fatty acids and PUFA has beneficial effects on insulin sensitivity (Risérus et al. 2009).

5.4 Cancer

Dietary habits remain one of the leading causes of cancer. Epidemiological studies have indicated that the people who eat saturated and unsaturated *trans* fats, mainly from fried meats, have the highest cancer risk (Bajinka et al. 2017). In the EURAMIC study, an ecological study, commenced in 1997, it has been proven that there is a positive association between *trans* fatty acid intake and the incidence of cancer of the breast and colon (Bakker et al. 1997; Kohlmeier et al. 1997).

5.5 Dementia

Studies have found that intake of *trans* fat is positively associated with the risk of dementia including Alzheimer disease. *Trans* fats tend to elevate plasma total and LDL cholesterol concentrations, which, in turn, may be associated with Alzheimer disease risk (Barnard and Bunner 2014).

5.6 Infertility

Trans fats are believed to cause infertility in men and women. In men, *trans* fatty acids cause adverse effects on reproduction including decrease in fertility, serum testosterone levels and sperm count, motility, and normal morphology of sperms. Extreme levels may lead to the arrest of spermatogenesis and testicular degeneration (Chavarro et al. 2014). Studies on fatty acid composition of semen samples of men undergoing infertility test found that *trans* fatty acids are present in human sperm and are inversely related to sperm concentration (Chavarro et al. 2011; Attaman et al. 2012). It is estimated that when *trans* fatty acid consumption in healthy men aged between 18 and 23 years increased from 0.37% of total calorie intake to 1.03% of total calorie intake, the sperm concentration decreased from 135×10^6 to 94×10^6 (Chavarro et al. 2014; Esmaeili et al. 2015). Thus, *trans* fats affect spermatogenesis. It is also found that *trans* fats may increase the risk of ovulatory infertility (Chavarro et al. 2007; Chavarro et al. 2011).

5.7 Other Negative Effects

There are no evidences to support the relationship between the *trans* fat intake and obesity; however, dietary *trans* fats could be metabolized differently and easily deposited in the adipose tissue, because the melting points of *trans* fats are much higher than those of non-*trans* fats (Ochiai et al. 2013). Further, *trans* fats contain calories in the same quantities as other edible fats. Thus, *trans*-fatty acid may cause excess weight (Stender and Dyerberg 2003). Incidences of allergic reactions (hay fever, atopic disorders, and asthma) are also found to be associated with the intake of *trans* fats (Stender and Dyerberg 2003).

6 Global Scenario of *Trans* Fats

Systemic review of data from 29 countries by Wanders and co-workers (2017) indicated that *trans* fat intakes range from 0.3 to 4.2% of total energy intake of which *trans* fat intake of seven countries is higher than the recommendation by the WHO (less than 1% of the energy intake). In 2010, *trans* fat intakes were within the range of 0.2 to 6.5% of total energy intake worldwide; thus, in the past 17 years, substantial reduction in industrial *trans* fat has been achieved by many countries including the United States, Canada, Netherlands, South Korea, Iran, and Australia (Micha et al. 2014; Downs et al. 2017; Wanders et al. 2017).

6.1 Regulations on *Trans* Fats in Selected Countries

Following the scientific evidence that *trans* fats are strongly associated with the risk of cardiovascular diseases, most countries have already set strict legal limits on *trans* fat content of foods. Currently, more than ten countries have adopted policies including mandatory labelling and bans at both the local and national level targeting the reduction of industrially produced *trans* fats from their food supply (Wu et al. 2017). Denmark was the first country in the world to set regulations related to *trans* fat in 2003 (Pérez-Ferrer et al. 2010). Denmark started to take measures to reduce *trans* fat following the report published in Lancet in 1993 (Willett et al. 1993). In 2003, the Danish Order on *trans* fats in oils and fats became effective (maximum of 2 g *trans* fats/100 g of oils or fats intended for human consumption) after the report recommending legislation on *trans* fats submitted by Danish Nutrition Council in 2001 (Pérez-Ferrer et al. 2010). Since 2006, the US-FDA has required that *trans* fats be declared on the nutrition facts panel of foods. The WHO has called for the elimination of *trans* fats from the global food supply. Recognizing the adverse health effects of *trans* fats, many countries implemented their national rules on *trans* fats, and many food manufacturers and retailers have been systematically removing them from their products in recent years.

Several European countries implemented voluntary strategies aimed at reducing the national consumption of *trans* fat through collaboration between industry and government. Mandatory labelling of *trans* fat content is not currently implemented in any of the WHO European Member States (WHO 2015).

Following the initiatives of Denmark, some other countries such as Switzerland (2008), Austria (2009), Iceland (2011), Hungary (2014), Norway (2014), and Sweden (2011) also implemented legislation on *trans* fats. All these countries have set a legal upper limit of 2 g of industrially produced *trans* fats per 100 g of fat or oil (WHO 2015). Intake of *trans* fat is relatively low in Australia compared to other countries (Wu et al. 2017). The Netherlands achieved a 0.8 g/day reduction in *trans* fat intake from 2.1 to 1.3 g/day by implementing regulation to put a healthier choices logo for food packages since 2006 (Hyseni et al. 2017).

Canada has achieved significant reductions in *trans* fat levels through multifaceted approaches such as mandatory nutrition labelling, the establishment of *Trans* Fat Task Force to develop recommendations and strategies to mitigate *trans* fat from Canadian foods, and monitoring of food products for *trans* fat levels (Pérez-Ferrer et al. 2010; Krenosky et al. 2012). Canada took measures to ban *trans* fat with effect from September 2018 after providing adequate time for the food industries to find suitable alternatives (Downs et al. 2017). *Trans* fat labelling has been mandatory in Hong Kong Special Administrative Region and Taiwan. (Wijesundera et al. 2007; Downs et al. 2013b).

The United States has imposed restrictions on the use of *trans* fats ingredients in food service establishments (US-FDA, 2014). In the United States, the final rule mandating labelling of the *trans* fat content in packaged foods was published on July 11, 2003, with an implementation deadline of January 1, 2006 (Camp et al. 2012). As a consequence, the food industries including large-scale food manufacturing organizations and food service establishments such as McDonald's, KFC, Starbucks, and Burger King have started reducing *trans* fat content in their products. The US-FDA has set a deadline, June 18, 2018, for the food manufacturers to get rid of *trans* fats by removing partially hydrogenated vegetable oils completely from the food supply (Laaninen 2016).

Despite the challenges, there are examples of success in reducing *trans* fat in the food supply by adopting voluntary approaches in Latin American countries such as Costa Rica and Argentina to get an adequate supply of healthy replacement oils for partially hydrogenated vegetable oils (Downs et al. 2015). In Slovenia, voluntary guidelines and regular public communication of the risks related to the *trans* fatty acid consumption alone resulted in significant effect on the *trans* fat levels in the food supply, even though sufficient removal of partially hydrogenated oils has not been achieved from foods (Zupaniˇc et al. 2018).

In India, vanaspati (partially hydrogenated edible oil mixture used as cooking oil and in fried snacks, baked goods, and street-vended foods) remains the major source of *trans* fat. Vanaspati is widely used since it is cheap and oxidatively stable for repeated heating (Downs et al. 2013a). In July 2013, the government of India (Food Safety and Standards Authority) set regulation on *trans* fat levels requiring the manufacturers of vanaspati to limit the *trans* fat content to 10% and also requiring to include *trans* fat content in labelling of packaged food. In December 2014, the regulation was amended to reduce *trans* fat levels to 5% in partially hydrogenated vegetable oils by August 27, 2016, which was then extended up to December 31, 2017 (Downs et al. 2015; Food Safety and Standards Authority of India 2017). Downs et al. (2015) concluded that multi-sectoral food chain approach would be effective in India and other low- and middle-income countries to reduce *trans* fat. This approach requires investment for the development of competitively priced shortenings and incentives for manufacturing foods using healthier oils.

In Malaysia, there are no legislations at the moment to limit the *trans* fat levels present in foods (Khean 2017). However, labelling guidelines are available for *trans* fat content in foods: "Low in *Trans* Fats" (<1.5% of 100 g food or < 0.75 g of 100 mL liquid) and "*Trans* Fat-Free" (<0.1 g of 100 g food or 100 mL liquid) (Azimah et al. 2013).

7 Alternative Methods for Partial Hydrogenation

Finding a replacement for partially hydrogenated vegetable oils is a significant challenge to the food industry to find out healthy replacements that give the same physical and sensory properties of end products as partially hydrogenated vegetable oils. Therefore, food technologists and scientists commenced exploring novel alternative methods for hydrogenation.

7.1 Novel Hydrogenation Techniques

Hydrogenation is a process of adding hydrogen to the double bonds of unsaturated fatty acids in the presence of a catalyst, in general nickel as explained in an earlier section of this chapter. The objective is to increase the oxidative stability of oils by reducing the degree of unsaturation and changing their physical properties, importantly, to change the liquid oils into plastic fats such as shortenings, margarine, and fat spreads (Martin et al. 2007). Modifications in the reaction conditions of hydrogenation process such as pressure, temperature, and catalyst can change the amount of *trans* fatty acids formed and also modify the properties such as melting point and solid fat content of oil (Dhaka et al. 2011).

Three strategies can be used during hydrogenation for reducing *trans* formation. First is increasing the hydrogen pressure so as to increase the amount of hydrogen on the catalyst surface. Second is using a less active catalyst with fewer active sites so as to ensure that the catalyst surface always has enough absorbed hydrogen near the active sites. This can be achieved by producing catalysts with smaller surface area and less activation or by pre-poisoning the catalyst and by blocking most of the active sites with a catalyst poison such as sulfur. Third is slowing the reaction down so as to allow more hydrogen movement to the catalyst surface before the fat molecule is released by the catalyst. This can be done by decreasing the temperature of the reaction (Campbell 2005).

Some novel hydrogenation techniques have also been proposed. Patented procedure is available to prepare low-*trans* shortenings by partial hydrogenation using conditioned catalyst. Edible oils are hydrogenated in a manner to minimize the formation of *trans*-stereoisomers. A catalyst (nickel) conditioned using organic acid phosphates and phosphoric acid discourages *trans*-stereoisomer formation without significantly negatively impacting the length of time required to form solids during hydrogenation (Higgins 2007).

King et al. (2001) have reported a procedure for the hydrogenation of soybean oil in supercritical carbon dioxide, hydrogen, and nickel catalyst with minor formation of *trans* products (King et al. 2001). Wright et al. (2003) have also reported a method for the hydrogenation of canola oil using mixed metal catalysts (nickel and palladium) and lower temperatures that promotes the formation of *cis* isomers and very low production of TFA (11%) (Wright et al. 2003). Lalvani and Mondal (2003) have designed a promising and innovative process for the hydrogenation of edible oils which consists of the electrochemical hydrogenation of oils at low temperature in the presence of formate as the electro-catalyst with nickel and palladium as catalysts. The use of low operating temperatures (<70 °C) restricts the formation of *trans*-fatty acid isomers to less than 10% of the oil content (Lalvani and Mondal 2003). Novel hydrogenation technique to produce partially hydrogenated vegetable oils rich in conjugated linoleic acids by modifying through pressure, temperature, and catalyst has been proposed (Dijikstra et al. 2008).

Enzymatic hydrogenation techniques are also possible to reduce the *trans* fats in foods using enzymes and pathways similar to that used by rumen microorganisms to produce oils of varying degrees of unsaturation (Loor et al. 2003).

7.2 The Use of Saturates

The natural oils such as coconut, palm, and palm kernel oils are saturated oils. Fractions high in solids can be separated by cooling below its melting point and separating the triglycerides with a higher melting point than the tempering temperature by centrifugation or filtering off from the liquid part. Fractions of palm and palm kernel oils are available commercially (Dhaka et al. 2011). Based on crystallization temperature, cooling rate, and pressure, a number of palm fractions of different composition and functionality can be produced. Saturated stearin palm oil fractions are used to produce cake shortenings, vanaspati (India), pastry margarines, soft and brick margarines, and low-fat spreads (Kaushik and Grewal 2017).

7.3 Structured Lipids

In recent years, edible oil structuring has gained considerable interest. These structuring methods include the creation of structured emulsions by organogelation and interesterification. The interesterified oils are emerging as the most promising alternative for the production of *trans* fat-free oils.

7.3.1 Edible Oleogels (Organogels)

An oleogel or organogel can be defined as a three-dimensional gel network containing an organic liquid entrapped within a thermo-reversible, anhydrous, and structured viscoelastic material, also referred to as oleogels if the organic phase is an edible oil (Kaushik and Grewal 2017). The structural and mechanical properties of structured emulsions and edible oleogels (ethylcellulose oleogels, plant-based wax oleogels, and monoacylglycerol-structured emulsions) can be tailored to mimic that of partially hydrogenated oil-based fat systems. These oil-structuring methods are promising techniques for replacing partially hydrogenated oil (Wang et al. 2016). Oleogelation is the process of converting liquid oil into gel-like material without modifying the chemical characteristics of oil. Oleogels can be applied to various food products to replace partially hydrogenated oils such as baked products, margarines and spreads, and chocolates with the comparable texture, stability, and sensorial properties (Patel and Dewettinck 2016).

Substances that form organogels with edible oils include lecithin, sorbitan tristearate, monoacylglycerides, a mixture of phytosterol and oryzanol, ricinelaidic acid, fatty alcohols, fatty acids, 12-hydroxystearic acid, wax esters, and waxes. Plant waxes are of great interest because of the low cost and availability. The gelation abilities of plant waxes have been studied, and for margarine and spread preparation, wax-based oleogels (sunflower wax, rice bran wax, and candelilla wax) are found to be the most suitable options (Hwang et al. 2013; Hwang et al. 2016; Kaushik and Grewal 2017).

7.3.2 Interesterification

Interesterification is the process of rearranging the distribution of fatty acids either chemically or enzymatically within and between the triacyl glycerol molecules; thus, only the fatty acid distribution is altered while the fatty acid composition remains the same. Interesterification modifies the melting and crystallization behavior of the fat, thus producing fats with the desirable physical properties necessary for the production of margarine or shortening fats without *trans* fats (Dhaka et al. 2011). Thus, interesterification has gained popularity as an alternative for partial hydrogenation to produce *trans*-free margarines, shortenings, and other spreads.

Chemical interesterification process produces full positional randomization of fatty acids on the glycerol backbone. Chemical interesterification is relatively cheap and used in industrial applications, particularly in Europe, to produce low- or zero-*trans* plastic saturated fats. Enzymatic interesterification catalyzed by positional specific lipases offers more control over the reaction products than chemical interesterification. Enzymatic interesterification is carried out under mild processing than chemical interesterification; thus, less by-products are formed (Kaushik and Grewal 2017).

7.4 Other *Trans* Fat Replacement Strategies

Traditional plant breeding or biotechnological methods are used to modify the fatty acid composition of oils, for example, high-oleic acid oils (high-oleic sunflower and canola oils), mid-range-oleic acid oils (mid-oleic sunflower and soybean oils), and low-linolenic acid oils (low-linolenic canola and soybean oils). These modification techniques can be used to formulate *trans*-free hardstocks (Dhaka et al. 2011). It is recommended that salad and frying oils should be developed with moderate levels of oleic acid (< 80%) and low linolenic acid (< 3%). Further, saturated fatty acids should be low (<7–8%) and linoleic acid at least 20–30%. Oils with this fatty acid profile have sufficient oxidative stability, thus eliminating the need for partial hydrogenation; thus, *trans*-fatty acid levels are not increased. Sunflower and canola oils are being modified and commercially available in several countries. Low linolenic canola oil genotypes with less than 3% linolenic acid are available in Canada (Warner et al. 2001).

The National Sunflower Association markets NuSun®, a mid-level (65%) oleic sunflower oil. The NuSun® sunflower germplasm lines were developed at the USDA Agricultural Research Service in Fargo, ND, by traditional plant breeding methods. Various other sunflower seed mutants have been engineered with mid-oleic acid levels (65% to 75% oleic acid) as well as hybrids that produce low levels of palmitic and stearic acids. NuSun® is used in the new zero-*trans* Frito-Lay® snacks and zero-*trans* fat Crisco shortening (Tarrago-Trani et al. 2006).

As a result of the newly introduced regulations, most of the fast-food chains have replaced frying fats by medium- to high-stability vegetable oils (such as high oleic oils), which has resulted in an elimination or reduction of *trans* fats in their products (Dhaka et al. 2011). The use of fat replacers which are ingredients that mimic the functionality and sensory properties of fat is another alternative. Fat replacers can be lipid, protein, or carbohydrate based. Suitable fat replacers can be selected based on the understanding of the food system.

7.4.1 *Trans* Fat Replacement in North America, Europe, China, Malaysia, and India

In North America, *trans* fat replacement includes chemically and enzymatically interesterified margarine/shortening oils, lauric fats for confections, palm-based shortening, baking shortenings made by modified hydrogenation technologies, and high-stability trait-modified oils (List 2014). In Denmark, after the introduction of legal limit of *trans* fat content, saturated fatty acids have been used as the main replacement. Palm oil is typically used in reformulating bakery foods (WHO 2015). In China, palm-based fat has partially replaced hydrogenated fats in most shortening and margarine recipes; however, this replacement has brought about some technical challenges (Zhang et al. 2014).

In India, vanaspati is the major source of *trans* fat (45–50%). Vanaspati is used as an all-purpose fat. Even though the government enforced regulations to reduce the *trans* fat content of partially hydrogenated oils and made labelling mandatory, the replacement solution has not been effective to date. Enzymatic interesterification has been proposed by the Food Safety and Standards Authority of India, and its application is limited and may take time to implement because it is a costly alternative for India (Dhaka et al. 2011).

8 Sri Lankan Perspective

8.1 Possible Sources

As explained earlier in this chapter, some countries such as Denmark, Canada, and the United States have achieved significant reductions in the *trans* fat content of foods.

The use of partially hydrogenated vegetable oils for cooking traditional dishes is common in Sri Lanka. Partially hydrogenated vegetable fats may contain high levels of *trans* fats up to 35–45%. Shortenings used in the production of baked goods in Sri Lanka are supposed to carry high levels of *trans* fats. Food produced using partially hydrogenated oils as a key ingredient such as margarines, shortenings, frying oils, baked products, confectionery products, deep-fried products, frozen pizza, coffee creamers, and many processed snack foods serve as the major sources of *trans* fats.

Foods fried above 180 °C for prolonged time using oils containing polyunsaturated fatty acids in restaurants or at home are a major source of *trans* fats. Furthermore, the reuse of frying oils many a time for frying snacks such as rolls, samosa, *wadei,* and cutlets leads to generation of significant quantities of *trans* fats which are subsequently absorbed by the fried products. Therefore, the snacks and other food items prepared and/or sold by the roadside vendors have become the main source of *trans* fats in Sri Lanka. A recent study carried out in the central province of Sri Lanka revealed that 95% of roadside snack makers use palm oil for frying as palm oil does not become rancid easily upon frying. It was observed that at times, oil is reused nearly 40 times within a single day (Jayawardena et al. 2014). Furthermore, the food items sold by the roadside vendors cost less and are, therefore, most likely to be consumed by people with low income. It is suspected that reused oil from food processing establishments and restaurants are collected by some organized groups for resale after bleaching.

9 Way Forward

9.1 Mitigating the Existence of *Trans* Fats in the Food Supply of Sri Lanka

Different countries have adopted different measures to mitigate the intake of *trans* fats. Data from other countries which have adopted the mitigation strategies show that the content of *trans* fats in their food supply has significantly decreased as a result of these efforts. Information on the extent of *trans* fat consumption in Sri Lanka is very much limited. Most of the Sri Lankan consume *trans* fats from various sources at significantly high levels that increase their risk for heart diseases. Thus, it is necessary to assess the extent of *trans* fat consumption and its relationship to the noncommunicable diseases, importantly heart diseases. According to the Ministry of Health, Nutrition and Indigenous Medicine, Sri Lanka, ischemic heart diseases are the leading cause of death in Sri Lanka since 1995 (Annual Health Bulletin 2015 2016). Thus, there is an urgent need for introducing policy changes. In 2011, the World Bank has urged Sri Lanka to bring laws to encourage good food processing practices and control *trans* fat content in food. Food regulatory authorities in Sri Lanka have not yet formulated any regulations regarding *trans* fat content in processed foods.

Even though the possible level of consumption of *trans* fat by the Sri Lankan population remains high, it is likely that the low-income groups may be exposed to much higher levels of *trans* fat as they consume processed foods available at relatively low cost. Thus, different strategies and policy options targeting different groups should be proposed to reduce the *trans* fat content in the daily diets. As mentioned in the review by Hyseni et al. (2017), these can be described as upstream or downstream interventions. Downstream interventions target individuals and involve behavioral approaches, whereas intermediate interventions target subgroups in workplaces, schools, or communities. Upstream interventions may take place at the population level involving regulatory approaches.

The government of Sri Lanka has prepared a draft labelling regulation which is available for public for comments. According to this draft regulation, the *trans* fat content should be included in the nutritional label (Food Labelling and Advertising Regulations 2015). However, legal limit has not been set for the *trans* fat levels for any food. As evidenced by other countries, labelling regulation can contribute much to achieve reductions in *trans* fat levels. Labelling can help keep the consumers informed of the *trans* fat levels in foods. Thus, health claims such as "*trans* fat-free" may help them select healthy choices. In addition, labelling regulations may accelerate product reformulation by the food industries. *Trans* fats must be declared on the nutrition label of conventional foods and dietary supplements on a separate line immediately underneath the saturated fatty acid content. In order to ensure that the industries are adhering to the labelling regulations, monitoring of *trans* fat content in food products is essential. The Sri Lankan government introduced traffic light labelling system to inform the consumers about the sugar levels in soft drinks. Such system may also be effective in *trans* fat labelling regulation as well.

The most effective technique to mitigate the *trans* fats in foods would be setting a legal limit for the content of *trans* fats in all foods, which can potentially reduce the risks associated with *trans* fats. However, the regulations only can be applied to foods those are labelled. It is quite challenging to regulate the *trans* fat content in food prepared and sold at restaurants, canteens, and eateries and foods prepared by the roadside vendors.

It is important to impose strict regulations on the *trans* fat content of imports. Shortenings are mainly imported from other countries for the bakery and confectionary industries. The shortenings manufactured without using partial hydrogenation are slightly expensive than the hydrogenated counterparts. Therefore, food processors tend to import the low-priced shortenings. The regulatory authorities should develop the capacity to quantify *trans* fat in foods. However, currently, there are only few places which have the capability to quantify *trans* fats. Without developing the capacity to quantify *trans* fats, the enforcement of the regulations would be challenging.

Another issue in enforcing the legal limit is the less availability of alternative fats such as modified fats or interesterified fats. The purpose of partial hydrogenation is to obtain semisolid fats with modified melting and crystallization behavior to be used for different purposes such as production of margarines and shortenings and as ingredients in bakery fats. There are some alternatives used in other countries as explained earlier in this chapter. However, decisions on which alternatives to be used are complicated because they involve availability of resources, facilities for research and development, and the acceptance of sensory quality of the food by consumers. The country has to face several challenges as financial investment and technical facilities; thus, application in Sri Lanka may take time. In order to tackle with these challenges, the country could seek for funds for research and development and reformulation of products. Moreover, most of the processors attempt to keep the cost of production low. The alternative materials are generally expensive; thus, the use of alternatives brings the prices up. Therefore, there will naturally be resistance from the processors against implementation of regulations.

Even though the public is increasingly aware of healthy foods, most of the people in Sri Lanka are not sufficiently aware of the *trans* fats and their health impacts. Thus, there is a need of more public education about saturated fats and *trans* fats. Mandatory food labelling and voluntary labelling and claims also could raise consumers' awareness about the health risks of high intake of *trans* fats and enable consumers to choose products with low-*trans* fat content.

It is high time for the health authorities to carry out nationwide survey on the consumption of *trans* fats. Further, guidelines should be established for local authorities to independently monitor *trans* fat levels at restaurants.

As explained earlier, frying oils also contribute to *trans* fat content in foods. Deep frying using oils containing polyunsaturated fatty acids such as sunflower and soybean oil produces *trans* fats. Therefore, these oils should not be used for deep frying. In Sri Lanka, coconut oil is the most suitable oil based on availability. The risk of formation of *trans* fats in coconut oil is minimum because of its high proportion of saturated fatty acids. Since frying foods at high temperature and oil reuse also produce *trans* fats, as in several European countries, temperature limit can be implemented.

10 Conclusion

Increased prevalence of noncommunicable diseases, especially cardiovascular diseases, among Sri Lankans is at least partially attributed to the high levels of *trans* fats in their diet. Thus, taking industrially produced *trans* fatty acids out of the Sri Lankan food supply will be an effective dietary intervention for reducing the risk of noncommunicable diseases. Many countries have already implemented policies to mitigate the presence of *trans* fats in the food supply and as a result achieved their target significantly to reduce the *trans* fat consumption. It is an urgent need in Sri Lanka to take initiatives to take out the *trans* fat from food supply to ensure that all population is consuming *trans* fat as low as possible which is less than 1% of energy intake. There are no drop-in solutions to be applied easily in order to achieve the targeted reduction in *trans* fat level. The reduction needs a systemic approach involving all sectors. Thus, taking *trans* fat out of the food supply in the country will be time-consuming and a complex issue; however, effective implementation of policies will help achieve the target and assure the welfare of the whole society in the country.

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