Trans fatty acids: Replacement technologies in food

Abstract

Trans fatty acids (TFA's) are the isomerization form of carbon double bonds and give desired physical and chemical properties as saturated fatty acids in food products. Some trans fatty acids occur naturally, while most of it is artificial. Major contributors of the TFA's in the diet are fried and baked foods, in which partially hydrogenated vegetable oils are used. Increasing epidemiological and biochemical evidence has suggested a direct link of consumption of TFA's rich food and various health disorders such as cardiovascular disease (CVD), diabetes, breast cancer etc. In response to the increasing risk of diseases and public health concerns, food and nutritional organization recommends that the intake of TFA's by all population groups should be kept as low as possible, which is about 1% of energy intake or less; and WHO (2004) has called for the elimination of TFA's from the global food supply. There is considerable interest in zero- and low trans fats containing food products including food manufacturers, and demand of such products is rising. For production of such type of food products, knowledge about the chemical nature, nutritional aspects of TFA's and role of food technologies available is required. Low TFA's food products can be manufactured with use of technologies such as electrochemical hydrogenation, organogelation, interesterification, fractionation and speciality oils etc. The present paper focused on chemistry, nature, nutritional aspect, method of analysis, labelling and various novel replacement technologies that have ability to mimic the functionality of saturated fats, give desired application in baked, fried and confectionary products with low or zero trans fatty acids.

Keywords: Cardiovascular diseases, Hydrogenation, Interesterification, Modified oils, Organogelation and Trans fatty acid

Introduction

Natural fats and oils are generally triesters of glycerols and fatty acids. Fatty acids represent the main class of lipids in the human diet generally embrace 90% of the fats in foods. These are aliphatic monocarboxylic acids that derived from hydrolysis of natural occurring oils and fats, generally as glycerol esters that form triacylglycerols (TAG). These are the compounds that are of interest when reporting lipid content labelling of fats and oils (Menaa et al. 2012 and Menaa et al. 2013). Fatty acids are classified on the basis of degree of saturation i.e. saturated fatty acids and unsaturated fatty acids. Saturated fatty acids are those which are solid at room temperature and having a single carbon-carbon bond. Unsaturated fatty acids are liquid at room temperature and divided into monounsaturated (single double carbon-carbon bonds) and polyunsaturated fatty acids (two or more double carbon-carbon bonds) (Kodali 2014). In the animal and plant kingdoms, unsaturated fatty acids show geometrical isomerism mainly as cis configuration. In this form, the hydrogen atoms attached on the same side of the double bond carbon chains while on the opposite side of the double bond carbon chains, giving the trans configuration, called trans fatty acids (TFA's) (Martin et al. 2007). Trans fatty acids (TFA's) can be produced by cis isomerization from natural source by enzymatic hydrogenation or biohydrogenation or artificial source by partial catalytic hydrogenation (PCH) (Menaa et al. 2013). Their manufacturing and use is in demand by industry because they are cheap, they are semisolid at room temperature which give longer shelf life and makes them easier to use. Human consumption of utmost TFA's i.e; partial hydrogenated vegetable oil (PHVO) could influence the higher threat of cardio vascular disease (CVD), infertility, endometriosis, gallstones, alzheimer disease, diabetes, breast cancer and colon cancer, and also interference with the production of essential fatty acids. In response to the rise in risk of diseases, WHO has called for the elimination of TFA's from the global food supply. From this perspective, there is considerable interest in zero- and low trans fats containing food products including food manufacturers, and current use of such products is rising (Downs et al. 2013). For getting such type of food products, manufacturers are moving on using the other technologies such as electrocatalytic hydrogenation, interesterification, fractionation, etc.

Isomerism of fatty acids: Cis & trans isomerism

Cis and trans isomers are geometric isomers as they differ from one another only in the way that the atoms are oriented in the space. In the cis arrangement, kinked geometry produced by chains on the same face of the carbon double bonds. In the trans arrangement, the chains are on the opposite faces of the carbon double bond and the chain is straight overall (Kodali 2014).

Chemical-physical properties of TFA's and their characteristics

TFA's exhibit particular physical and chemical properties that analytically extricate them from cis –fatty acids. Physical and chemical properties of cis fatty acids and trans fatty acids are depicted in Table 1. Irrespective important health concerns, TFA's are more helpful than cis –fatty acids for the production of fat foods, because they can improve their structure, lubrication, and textural properties (consistency/hardness, brittleness, springiness, and chewiness); increase their shelf life, flavor stability, emulsion stability; decrease food sensitivity to oxidation; increase their stability against liquefaction; and increase their stability during frying at high temperature and storage at room temperature (Eckel et al. 2007).

Nature & sources of trans fatty acids

On the basis of origin, TFA's are classified as natural or artificial & their contribution to TFA's are 21 and 79% respectively. Naturally TFA's are derived from animal (meat & dairy products) and plant kingdom. In animals, TFA's are found in ruminant milk fats produced by biohydrogenation of feed-derived polyunsaturated fatty acids (PUFA) by rumen bacteria. When dietary triglycerides, phospholipids, and glycolipids enter a dairy cow's rumen, which contains 40-50 liters of fluid with bacteria 10^{10}-$10^{11}$and 10^{6} protozoa per milliliter, the ester linkages of these lipids are first hydrolyzed by rumen bacteria hydrolases followed by biohydrogenation. The initial step in this process involves the conversion of a cis-12 double bond to a trans-11 configuration in polyunsaturated fatty acids, followed by the hydrogenation of a cis-9 double bond (Figure 1). Therefore, the fat from ruminant animals contain vaccinic acid (11-trans 18:1) and rumenic acid (9c, 11t-18:2). Rumenic acid is the major conjugated fatty acid in ruminant fats which regarded as detrimental to health (Martin et al. 2007; Dijkstra et al. 2008; Park 2009; and Kodali 2014).

Various industrial processes which leads to the production of artificial TFA's in food products are catalytic hydrogenation, deep fat frying & deodorization or refining of oils (Dijkstra et al. 2008). In these processes, catalytic hydrogenation was started in 1890 to improve oxidative stability of oils. This process was first described by French chemist Paul Sabatier by using nickel catalyst to hydrogenate the vegetable oils. The saturated fatty acids are formed with complete hydrogenation. However, partial hydrogenation results in a mixture of cis and trans-fatty acids (Remig et al. 2010). Frying is one of the oldest food preparation method (Rosell 2001). The formation of TFA's during food frying is closely related to the temperature and time of processing (Sanibal and Mancini-Filho 2004).When partially hydrogenated fats are used, the production of TFA's is usually lower. Though the high initial contents of these acids resulted in a larger concentration of trans isomers in fried foods (Romero et al. 2000). Tasan and Demirci (2003) observed that the TFA's content of linoleic acid increased many fold at the end of refining process and deodorization step at 230°C for 2 hr.

TFA's are found in almost all food product categories that contain a source of dietary lipids and their amount and nature differs with the origin and composition of the lipids used in food products. The common sources of trans fat and the level of trans fat content in these products (Table 2). The trans fat content of hydrogenated fats varies from 5% to 40%, based on the extent of hydrogenation whereas beef and dairy products contribute 2 to 5% (Kodali 2014). In Indian population, mean TFA's intake per day ranged from 0.09 to 0.33g following consumption of edible oils and fats (Dixit and Das 2012).

Nutritional aspects of trans fatty acids

Scientific discoveries establish a link between dietary consumption of cholesterol and increased risk of cardiovascular disease (CVD), breast cancer (Kohlmeier et al. 1997), preeclampsia (Yli-Jama et al. 2002), colon cancer (Slattery et al 2001), diabetes (Ghafoorunissa 2008), obesity (Kavanagh et al. 2007) and allergy (Willett et al. 1993) resulted in significant intake of partially hydrogenated vegetable oils, which is the primary source of trans fatty acids. Based on their sources and biological activities, TFA's can be further divided into conjugated or non-conjugated TFA's. The conjugated TFA's that are naturally present in foods from ruminant sources, were first reported by Pariza and his group, investigated the variety of biological activities of Conjugated linoleic acid (CLA) (Park and Pariza 2007). Conjugated linoleic acid also referred to as ruminant TFA's, is a mixture of geometric and positional isomers, at different positions of carbon double bonds [9, 11], [10, 12], [8, 10], [7, 9] and [11, 13] are detrimental to health (i.e; anticancer, antiantherogenic, anti-adipoenic, antidiabetogenic and anti-inflammatory) while nonconjugated acids are referred to as industrial TFA's which are produced from partially hydrogenated vegetable oils. Mozaffarian et al. (2009) studied that a higher CVD risk is linked to industrial sources, whereas ruminant fat contains low quantity of TFA's (<6% FA's), the amounts of ruminant TFA's consumption are low in most countries (generally <1% of energy intake). So, on a par when the total ruminant fat intake is relatively high, the probable level of TFA's is still very modest and is not related to CVD risk. It has been indicated that industrial TFA's are the main source of TFA's and also taken as a major health concern with regard to CVD risk (Dijkstra et al. 2008 and Park 2009). TFA's consumption also adversely affected blood lipids and lipoproteins beyond changes in LDL and HDL. Compared with MUFA or PUFA, TFA's raised fasting triglyceride levels (Mozaffarian and Clarke 2009). A study carried out by Gupta et al. (2006) on the frequency and prevalence CVD in different states of India and reported a positive correlation of CVD mortality with dietary consumption of fat. Punjab was highest (0.36% to 0.43%), whereas Himachal Pradesh was lowest (0.075% to 0.1%) in CVD mortality rate.

Trans Fats Replacement Technologies

During the past 10 years, various substitutes to trans fats have been suggested (Eckel et al. 2007). With public health concerns, there is considerable interest in zero and low trans fat among food formulations and current use of such products is increasing (Dhaka et al. 2011) and the global manufacturing units switching to alternative processes in order to reduce or eliminate TFA's and produce healthier fat products (L'Abb´e et al. 2009; Menaa et al. 2012). There are four fundamental strategic technologies that have the ability to mimic the functionality of solid fat with zero or low trans fat content (Menaa et al. 2013 and Kodali 2014). These strategies and their functionalities are depicted (Table 3).

Modified hydrogenation process Trans-unsaturated fatty acids are generated during the partial hydrogenation of vegetable oils, enhanced oxidative stability, better shelf-life, improved mouth-feel, plasticity and flavour (Jang et al. 2005; Minihane and Harland 2007; Skeaff 2009). The pervasive presence of PHVOs throughout the global food supply in bakery products (cakes, biscuits, bread, crackers, pies, etc), deep-fried fast foods, snack foods, confectionery products and table spreads corroborates to their commercial value and convenience. However, due to increased distress about TFA's on health claims new hydrogenation processes such as precious catalyst hydrogenation, electrocatalytic hydrogenation and supercritical fluid state hydrogenation have been suggested to reduce trans fatty acids in hydrogenated vegetable oils (Jang et al. 2005 and Skeaff 2009). New hydrogenation processes to produce hydrogenated vegetable oils rich in high quantities of conjugated linoleic acids by modifying through pressure, temperature and catalyst have been reported (Dijkstra et al. 2008). King et al. (2001) reported a procedure for the hydrogenation of soybean oil in hydrogen, supercritical carbon dioxide, and nickel catalyst with minor formation of trans products. Wright et al. (2003), at the University of Toronto, have also studied a method for the hydrogenation of canola oil using mixed metal catalysts (palladium and nickel) at low temperature that promotes the production of very low of TFA's (11%). List et al. (2007) reported that shortenings produced by conventional hydrogenation consisted of 12 to 25% TFA's and 37% saturates, whereas shortening fats produced electrochemically had reduced TFA's and saturates content. Electrochemical hydrogenation, a promising route to low-trans spread and liquid margarine resulted in about 4% TFA's compared to commercial margarine/spread oils containing 8–12% TFA's.

Structured oils The potential for structuring edible oils using food grade ingredients is a dynamic area of research. Hardstock fat replacement with unsaturated oils reduces, or in many cases eliminates, hard textural properties; therefore, novel structuring methods are accepted to give hard-like qualities to vegetable oils, thus improving health and functionality. These structuring methods include the creation of structured emulsions by organogelation and interesterification, (Zetzl et al. 2012).

Organogelation An organogel can be defined as a three-dimensional gel network containing an organic liquid entrapped within a thermo-reversible, anhydrous and structured visco-elastic material, also referred to as oleogels if the organic phase is an edible oil. This gel network is formed by the self-assembly of organogelator molecules at a relatively low concentration; which are of low molecular weight compounds that are able to gelling organic solvents. In recent years, this field of organogelling has attracted considerable attention and interesting because it raises not only fundamental questions about the requirements for their formation but also provide a wide range of potential applications like pharmaceutics, food, cosmetics, etc can be identified. As it would be extremely attractive if ultimately lipid phase structuring could be as flexible as water phase structuring (Bot et al. 2009). Especially in food application, organogels have potential as one of the most promising substitute to saturated fatty acids-containing hardstocks used in production of structured products such as shortenings, spreads and margarines. Substances shown to form organogels with edible oils consist of lecithin, sorbitantristearate, 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 due to low cost and their availability. The gelation abilities of plant waxes have been investigated. There have been approved as food additives and some waxes including beeswax, candelilla wax and carnauba wax are listed as GRAS (Generally Recognized as Safe) (Hwang et al. 2013). Oleogelator compounds need to meet certain physicochemical properties like: (a) affinity for oil

(b) surface activity and self assembling properties (c) undergo higher structural arrangement and (d) preferably display thermo-reversible properties such as crystallization (Patel et al. 2013). Based on this understanding, Patel et al. (2014) recently identified novel use of shellac as an oleogelator in chocolate paste and reported no ‘oiling-out’ during storage at elevated temperature (30 °C) for several weeks.

Interesterification Interesterification involves exchanging fatty acids between the TAG’s in a mixture. It is a catalytic reaction, involving the hydrolytic release of some fatty acids, and their random reattachment to the glyceride. The reaction is catalyzed chemically or by enzymes. Interesterification has a proven track record in terms of its ability to tailor the consistency of fats and oils. When blends of palm hardstocks and vegetable oils are chemically randomized, products with a range of consistencies suitable for margarine, shortening, and confectionary applications are produced (Rønne et al. 2005). Interesterification usually results in a lowering the melting range of blends by eliminating the highest melting TAG’s present in the hardstock fats (Noor et al. 2002). Interesterification also change the polymorphic behaviour of blends, creating a β'-crystal. This type of crystal provides a smooth consistency and desirable functionality in applications such as whipped toppings and cake batters (Norizzah et al. 2004). Interesterification can be conducted enzymatically or chemically. Chemical interesterification (CIE) process is generally random and produces full positional randomization of the acyl groups on the glycerol backbone. Chemical interesterification is relatively cheap and used in industrial applications, particularly in Europe, to produce plastic saturated fats with a minimum level of trans fatty acids. Enzymatic interesterification (EIE) offers more control over the reaction products than CIE. Enzymes are highly specific or selective to cleave specific ester bonds. EIE requires low temperature for processing than CIE, so lesser thermal degradation occurs. Studies reconnoitered the storage stability of margarines produced by different blends [interesterified coconut oil and palm stearin (30/70), blended with sunflower oil in 50:50 ratio] by CIE and EIE methods and compared the physico-chemical properties. Margarine produced from EIE and CIE fat both had similar physical properties in terms of color, hardness, crystal form and dropping point. Sensory panel evaluations could not recognize any clear difference between the margarines, but the oxidative stability of the margarine produced from enzymatic interesterification was better when stored at 25°C (Zhang et al. 2006). Studies have been carried out on blends (wt %) of palm stearin or coconut oil and soybean oil or fully hydrogenated soybean oil, both in different ratios (Zhang et al. 2004); butterfat or rapeseed oil 70/30 (Ronne et al. 2005a); palm stearin or palm kernel olein in different ratios (Lai et al. 1998; and Chu et al. 2001); palm stearin or soybean oil 55/45 (Osorio et al. 2005); palm stearin or coconut oil 75/25 (Zhang et al. 2001) and 70/30 (Chang et al. 2005 and Zhang et al. 2006); palm stearin or palm kernel oil or sunflower oil 55/25/20 (Osorio et al. 2006); palm stearin or sunflower oil 40/60 (Lai et al. 1998). All these studies revealed that EIE produced trans-free fats can meet industrial demands for the production of margarine and thus can be used as a substitute to partially hydrogenated types (Costales-RodrÃguez et al. 2009).

Fractionation The controlled crystallization of triacylglycerol result in the separation of a solid phase (stearin) and a liquid phase (olein), and these, in turn, can be further fractionated (Figure 2) (van Duijn et al. 2006). On the basis of various factors such as crystallization temperature, cooling rate, and amount of pressure applied during the filtration, a number of palm fractions of different composition and functionality can be produced. Palm oil can be an excellent natural candidate for fractionation and fat blending due to its significant portion of high melting triglycerides and β’ crystals (Lida and Ali 1998; Sundram 2007). However, to maximize the use of palm oil as a blending source, it is necessary to fractionate the palm oil (Jeyarani and Reddy 2003). Palm oil fractions can be used in production of the formulations such as cake shortenings, vanaspati (Indian subcontinent), pastry margarines, soft and brick margarines and low fat spreads (Berger and Idris 2005). Mayamol et al. (2004) reported the use of palm stearin or rice bran oil in production of zero trans fat containing shortening.

Speciality oils /genetically modified oils The better understanding of plant genetics such as mutation and transgenic technologies, unraveling of enzymatic pathways involved in the triglyceride production is offering a great possibility for the plant breeders to include a range of fatty acid profiles into oilseed crops (Napier and Graham 2010; Wilson and Hildebr 2010; Wilson 2012). Thus, alteration of seed composition using biotechnological tools represent the most favorable strategy to increase the overall supply of high-oleic oil crops and offering high-quality products containing both low-TFA’s content and low-SFA’s (Wilson 2012). A number of high oleic oils showing different functionality as depicted in Table 4, including canola, sunflower, and safflower, are currently available on the market (Menaa et al. 2013 and Kodali, 2014).Till now, only a few private companies have taken USDA regulatory certification to launch commercial production of oilseed varieties with genetically enhanced oils of different fatty acid profile such as Clear ValleyTM and OdysseyTM mid-to-high-oleic canola oils and high-oleic sunflower oils, NexeraTM Omega-9 canola and Omega-9 sunflower oils, PlenishTM high-oleic soybeans from E. I. du Pont de Nemours and Co. (Wilmington, DE, USA) (Sebastian et al. 2012), and Vistive- GoldTM low saturated high-oleic soybeans from the Monsanto Co. (St. Louis, MO, USA) (Talbot 2014). Vistive-GoldTM soybean oil consists more than 74% oleic acid in addition to about 3% palmitic acid, less total SFA’s and TFA’s concentrations while preserving the overall acceptability of a partially hydrogenated frying shortening i.e, improvement in oxidation stability, polymer buildup reduction during frying and sensory acceptability (Ulmasov et al. 2012). As per the descriptive sensory profile of soyabean oil reported by Talbot (2014) it has hazy appearance, lard aftertaste, gluey aroma, yeasty aroma by mouth, pasty and umami taste were higher as compared to Plenish soybean oil.

Methods of analysis

There are three methodolgies such as gas chromatography, mid infra red and near infra red spectroscopy for the estimation of TFA's in food products (Table 5). These techniques are capable of determining total SFA, TFA's, MUFA and PUFA needed for food labelling. These are non destructive methods of analysis, very sensitive and accurate. Data interpretation is simple in case of mid infra and near infra methodologies as described.

Labelling

The Food Safety and Standard Authority of India (FSSAI) have also commenced the labeling of TFA's content of fats along with saturated, mono-unsaturated and poly-unsaturated fatty acid contents of the packaged food. If a nutritional or health claim is made by food manufacturer (Figure 3), then it is mandatory to declare TFA content on the nutritional information labels along with other dietary fatty acids. The TFA's in PHVO (vanaspati), according to the FSSAI recommendation, should be below 10 % (Dhaka et al. 2011). The FSSAI also recommends that there should be mandatory labeling of TFA's and saturated fatty acid content (SFA) of all edible fats and oils.

Conclusion

During the past 10 years, a number of alternatives to trans fats have been proposed. With public health concerns, there is considerable interest in zero and low trans fat among food formulations. The current use of such products is increasing and the global manufacturing units switching to alternative processes in order to reduce or eliminates TFA's and produce healthier fat products. There are four core strategic technologies that have the ability to mimic the functionality of solid fat with zero or low trans fat content. These are modified hydrogenation process, structured oils (oleogelation and interesterification), fractionation and specialty oils/ genetically modified oils.

Modified hydrogenation process give health promoting hydrogenated vegetable oils containing high levels of conjugated linoleic acids and has applicability in baking shortenings and spreads. Structured oils are produced by structuring and reshuffling of fatty acids to get desired physical and chemical properties by oleogelation and interesterification. It imparts solid-like qualities to vegetable oils Fractionation enables to get desired functionality by controlled crystallization process to get β' crystals which give applicability to use in baked shortenings, margarines, etc. Specialty oils/Genetically modified oils is new approach of plant breeding to get rid of trans fatty acids and to have high content of oleic, linolenic and stearic fatty acids with desired physical properties at primary stage of crop improvement. If enable them to use in various food product applications such as confectionary, bakery and frying.

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Figure 1: Biohydrogenation of linoleic and α-linolenic acid in the rumen

Figure 2: Fractionation of palm oil in different fractions

Figure 3: Nutrition labelling of TFA contaning food products

Table 1: Properties of Cis and Trans isomers

Table 2: Level of TFA in various food products

Table 3: Replacement technologies, physical characteristics and functionality

Table 4: Characteristics and fatty acid profile of different trait enhanced oils

Table 5: Different methods of TFA’s analysis

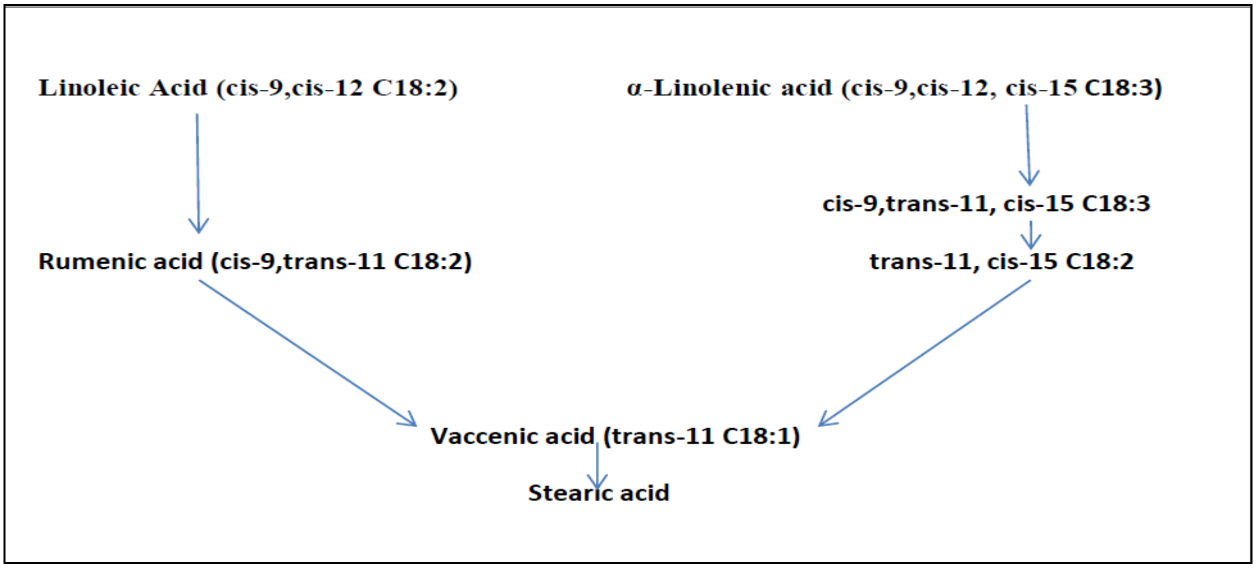


Figure 1: Biohydrogenation of linoleic and α-linolenic acid in the rumen

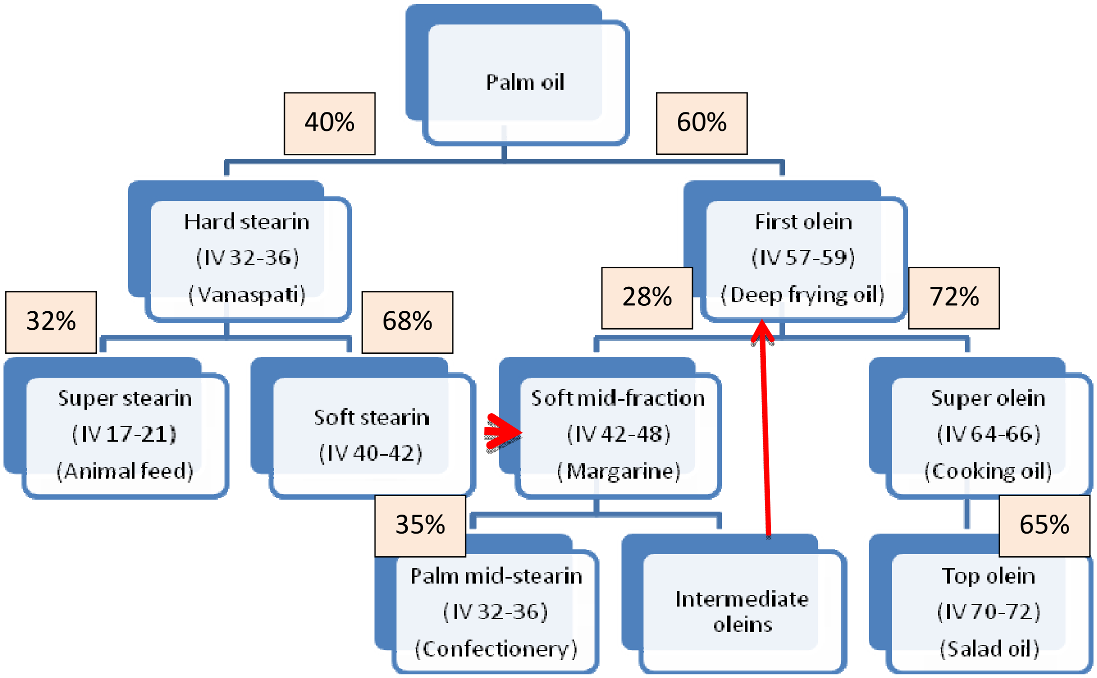
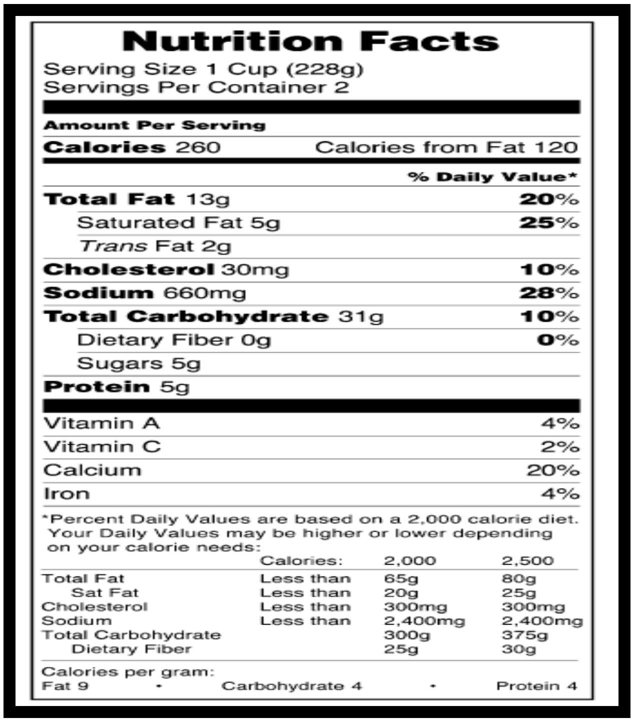


Figure 2: Fractionation of palm oil in different fractions



Nutrition Facts

Serving Size 1 Cup (228g)
Servings Per Container 2

Amount Per Serving

Calories 260 Calories from Fat 120

% Daily Value*

Total Fat 13g	**20%**
Saturated Fat 5g	**25%**
Trans Fat 2g	
Cholesterol 30mg	**10%**
Sodium 660mg	**28%**
Total Carbohydrate 31g	**10%**
Dietary Fiber 0g	**0%**
Sugars 5g	
Protein 5g	
Vitamin A	4%
Vitamin C	2%
Calcium	20%
Iron	4%

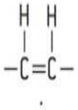
*Percent Daily Values are based on a 2,000 calorie diet. Your Daily Values may be higher or lower depending on your calorie needs:

	Calories:	2,000	2,500
Total Fat	Less than	65g	80g
Sat Fat	Less than	20g	25g
Cholesterol	Less than	300mg	300mg
Sodium	Less than	2,400mg	2,400mg
Total Carbohydrate		300g	375g
Dietary Fiber		25g	30g

Calories per gram:
Fat 9 • Carbohydrate 4 • Protein 4

Figure 3: Nutrition labelling of TFA contaning food products

Table 1: Properties of Cis and Trans isomers

Properties	**Cis**	**Trans**
Structure		
Occurrence	More common in nature	Rare in nature
Geometry	Hydrogen atoms on the same side	Hydrogen atoms on opposite sides

Symmetry	Less	more
Packing	Less	more
Melting point	Low	high
Thermodynamic stability	Less	more
Density	Less	more
Solubility	More	less

Table 2: Level of TFA in various food products

S. No.	**Food Products**	**Level of TFA**	**References**
1.	Hydrogenated vegetable oils	10-45%	Kala et al. 2012
2.	Refined oils	0.5-5.6%	Kala et al. 2012; Dixit and Das 2012
3.	Butter	0.65-3.2%	Haung et al. 2006; Kuhnt et al. 2011
4.	Margarine	0.04-34.96%	Haung et al. 2006; Kroustallaki et al. 2011; Meremae et al. 2012
5.	Shortenings	0.14-39.50%	Meremae et al. 2012
6.	Baked foods	4.5%	Meremae et al. 2012
	Cakes	5.05%	Cakmak 2011
	Crackers & cookies	0.51-3.81%	Haung et al. 2006
7.	Fried foods		
	French fries	0.99-5.63%	Haung et al. 2006; Meremae et al. 2012

	Potato crisps	0.01-0.282%	Cakmak 2011; Albuquerque et al. 2011
	Chicken patties, nuggets	0.93-3.33%	Haung et al. 2006
8.	Animal products	21%	Frost and Sullivan 2009

Table 3: Replacement technologies, physical characteristics and functionality

S. No.	Replacement Technologies	Type of oil	Physical characteristics	Functionality/Application	TFA level	Reference
i.	Electrochemical hydrogenation (Pd-Co catalyst)	PHSO (High stearic content)	S.F.C. at 33◦C is 31%, Dropping point (◦C) is 37.4	Baking shortening & spreads	6.4 to 13.8 %	List et al. 2007
ii.	Structured oils/Oleogels Structured oils/Oleogels	Canola + Soybean + Flaxseed oil oleogel (consisting 10% ethylcellulose + 90% vegetable oil)	Improved texture (chewiness & hardness)	Saturated fat reduction in frankfurters	Low TFA	Zetzl et al. 2012
		Shellac oleogel	No oiling out at 30◦C, improved oil binding property, emulsifier-free w/o emulsions	Spreads, chocolate paste, cakes	Zero TFA	Patel et al. 2014 & Patel et al. 2013
		12-hydrostearic acid	Fat bloom retarded	Cream filled chocolate		Hughes et al. 2009
		Plant wax + Soybean oil	High M.P., low saturates, comparable SFC at (25-35◦C) is 1 to 6% and dropping point to commercial oils	Margarine	Low TFA	Hwang et al. 2013
		90% sunflower+10% rice bran oil	Higher melt down resistance, higher overrun compared to high oleic sunflower oil	Icecream		Botega et al. 2013
iii.	Interesterification	Chemical interesterification Olive oil + palm stearin (40:60, 30:70)	More plastic blends, lower M.P., S.F.C. &increased diunsaturation	Margarine, shortening, fat spreads	Zero TFA	Silva et al. 2010
		Palm stearin + Soybean oil (70:30)	Enzymatic interesterification give better oil quality than chemical interesterification	Margarine	<0.1%	Costales-Rodriguez et al. 2009
		Pine nut oil: Plam stearin (40:60, 30:70), 40.4% Palmitic, 29.5% oleic	S.F.C. at 25◦C is 23.6%-36.2%, β' crystals are formed	Margarine	Zero TFA	Adhikari et al. 2010
iv.	Fractionation	Palm stearin: Rice bran oil (50:50) High PUFA	S.F.C. at 40-10◦C is 10-50%	Shortening	Zero TFA	Mayamol et al. 2004

Table 4: Characteristics and fatty acid profile of different trait enhanced oils

Trait enhanced oil	**Fatty acid profile**					**Physical property**	**Functionality**	**Application**
	Saturated		**Unsaturated**					
	Palmitic acid C16:0	Stearic acid C18:0	Oleic acid (n-9) C18:1	Linoleic acid(n-6) C18:2	α-Linolenic acid(n-3) C18:3			
Mid-oleic sunflower	5	4	65	25	1	65% oleic	Improved shelf life	Deep frying (snacks)
Hi-oleic sunflower	4	4	86	4	1	70-85% oleic acid, <10% Saturated fatty acid, < 1% TFA	High stability	Frying
Hi-oleic canola	3	4	65	24	4	high-oleic w-9	Improved taste with high stability	Frying
Hi-oleic sunflower	4	4	86	4	1	high-oleic w-9	Longer frying life	Frying
Low-linolenic soybean	-	-	-	-	-	<3% linolenic acid	Improved taste and sensory score	Frying and Baking
Low-linolenic/mid-to high-oleic soybean	7	4	75	7	1-3	<3% linolenic acid	Improved taste and sensory score, longer shelf life	Frying and Baking
Low-linolenic/high-oleic, high stearic soybean	-	-	-	-	-	High stearic	Provide functionality as solid fat	Baking

Source: Talbot (2014)

Table 5: Different methods of TFA's analysis

Methodolgy	GC	Mid-IR	Near-IR
Scope of determination	Fatty acid profile	Total trans fatty acids only	Fatty acid proile
Allows determination of total SFA, trans FA, MUFA, PUFA needed for food labelling	Yes	No	Yes
Calibration requirement	Use of an internal standard	Generation of a univariate calibration function	Development of multifunctional calibration mode
Sample	Yes	No	No
Solvent disposal	Yes	No	No
Nondestructive	No	Yes	Yes
Data interpretation	Complex	Simple	Simple