Advances in Research
9(5): 1-14, 2017; Article no.AIR.33297
ISSN: 2348-0394, NLM ID: 101666096

SCIENCEDOMAIN *international*
www.sciencedomain.org

Trans Fatty Acids: Replacement Technologies in Food

Isha Kaushik[1*] and Raj Bala Grewal[1]

[1]Centre of Food Science and Technology, CCSHAU, Hisar, Haryana, India.

Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

Article Information

DOI: 10.9734/AIR/2017/33297
Editor(s):
(1) Carmen Lizette del Toro Sanchez, Department of Food Research, University of Sonora, Mexico.
Reviewers:
(1) Eliton da Silva Vasconcelos, Federal University of São Carlos – UFSCar, Brazil.
(2) Carina Lorena Fernández, Universidad Nacional del Chaco Austral, Argentina.
Complete Peer review History: http://www.sciencedomain.org/review-history/18937

Review Article

Received 8th April 2017
Accepted 22nd April 2017
Published 6th May 2017

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.

**Corresponding author: E-mail: ishakaushikfst@gmail.com;*

Keywords: Cardiovascular diseases; hydrogenation; interesterification; modified oils; organogelation and trans fatty acid.

1. 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 [1,2]. 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) [3]. 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) [4]. 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) [2]. 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 [5]. For getting such type of food products, manufacturers are moving on using the other technologies such as electrocatalytic hydrogenation, interesterification, fractionation, etc.

2. ISOMERISM OF FATTY ACIDS: CIS AND 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 [3].

3. CHEMICAL-PHYSICAL PROPERTIES OF TFA'S AND THEIR CHARACTERISTICS

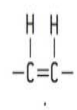
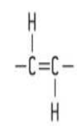
TFA's exhibit particular physical and chemical properties that analytically extricate them from cis –fatty acids. Physical and chemical properties of cis fatty acids and trans fatty acids are depicted in Table 1. Irrespective important health concerns, TFA's are more helpful than cis –fatty acids for 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 [6].

4. NATURE AND 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 (Fig. 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 [4,7,8,3].

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 [7]. 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 [9]. Frying is one of the oldest food preparation method [10]. The formation of TFA's during food frying is closely related to the temperature and time of processing [11]. 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 [12]. [13] observed that the TFA's content of linoleic acid increased many fold at the end of refining process and deodorization step at 230℃ for 2 hr.

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

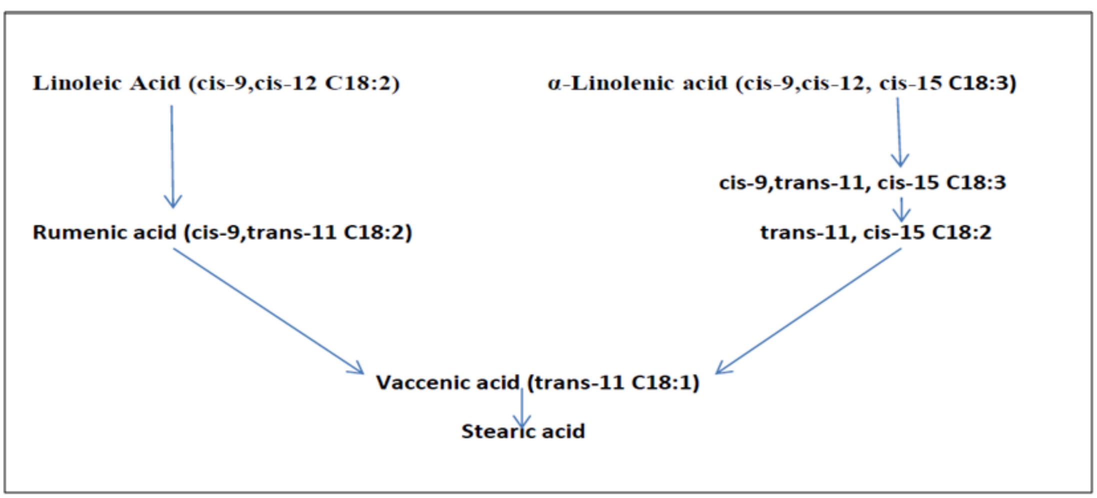


Fig. 1. Biohydrogenation of linoleic and α-linolenic acid in the rumen

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% [3]. In Indian population, mean TFA's intake per day ranged from 0.09 to 0.33 g following consumption of edible oils and fats [14].

5. 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 [15], preeclampsia [16], colon cancer [17], diabetes [18], obesity [19] and allergy [20] 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) [21]. 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. [22] 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 [8]). 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 [23]. A study carried out by [24] 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.

Table 2. Level of TFA in various food products

S. no.	Food products	Level of TFA	References
1.	Hydrogenated vegetable oils	10-45%	[25]
2.	Refined oils	0.5-5.6%	[25]
3.	Butter	0.65-3.2%	[26, 27]
4.	Margarine	0.04-34.96%	[26,28,29]
5.	Shortenings	0.14-39.50%	[29]
6.	Baked foods	4.5%	[29]
	Cakes	5.05%	[30]
	Crackers & cookies	0.51-3.81%	[26]
7.	Fried foods		
	French fries	0.99-5.63%	[26.30]
	Potato crisps	0.01-0.282%	[30,31]
	Chicken patties, nuggets	0.93-3.33%	[26]
8.	Animal products	21%	[32]

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℃ is 31%, Dropping point (℃) is 37.4	Baking shortening & spreads	6.4 to 13.8%	[33]
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	[34]
		Shellac oleogel	No oiling out at 30℃, improved oil binding property, emulsifier-free w/o emulsions	Spreads, chocolate paste, cakes	Zero TFA	[35,36]
		12-hydrostearic acid	Fat bloom retarded	Cream filled chocolate		[37]
		Plant wax + Soybean oil	High M.P., low saturates, comparable SFC at (25-35℃) is 1 to 6% and dropping point to commercial oils	Margarine	Low TFA	[38]
		90% sunflower+10% rice bran oil	Higher melt down resistance, higher overrun compared to high oleic sunflower oil	Icecream		[39]
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	[40]
		Palm stearin + Soybean oil (70:30)	Enzymatic interesterification give better oil quality than chemical interesterification	Margarine	<0.1%	[40]
		Pine nut oil: Plam stearin (40:60, 30:70), 40.4% Palmitic, 29.5% oleic	S.F.C. at 25℃ is 23.6%-36.2%, β' crystals are formed	Margarine	Zero TFA	[41]
iv.	Fractionation	Palm stearin: Rice bran oil (50:50) High PUFA	S.F.C. at 40-10℃ is 10-50%	Shortening	Zero TFA	[42]

6. TRANS FATS REPLACEMENT TECHNOLOGIES

During the past 10 years, various substitutes to trans fats have been suggested [6]. 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 [43] and the global manufacturing units switching to alternative processes in order to reduce or eliminate TFA's and produce healthier fat products [44,1]. There are four fundamental strategic technologies that have the ability to mimic the functionality of solid fat with zero or low trans fat content [2,3]. These strategies and their functionalities are depicted (Table 3).

6.1 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 [45,46,47]. 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 [45,47]. 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 [7]. [48] reported a procedure for the hydrogenation of soybean oil in hydrogen, supercritical carbon dioxide, and nickel catalyst with minor formation of trans products. [49], 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%). [33] 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.

6.2 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, [34].

6.3 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 [50]. 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) [38]. 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 [36]. Based on this understanding, [35] recently identified novel use of shellac as an oleogelator in chocolate paste and reported no ‘oiling-out’ during storage at elevated temperature (30℃) for several weeks.

6.4 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 [51]. Interesterification usually results in a lowering the melting range of blends by eliminating the highest melting TAG’s present in the hardstock fats [52]. 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 [53]. 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℃ [54]. 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 [55]; butterfat or rapeseed oil 70/30 [56]; palm stearin or palm kernel olein in different ratios [57,58]; palm stearin or soybean oil 55/45 [59]; palm stearin or coconut oil 75/25 [60] and 70/30 [61,54]; palm stearin or palm kernel oil or sunflower oil 55/25/20 [59]; palm stearin or sunflower oil 40/60 [57]. 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 [40].

6.5 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 (Fig. 2) [62]. 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 [63,64]. However, to maximize the use of palm oil as a blending source, it is necessary to fractionate the palm oil [65]. 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 [66]. [42] reported the use of palm stearin or rice bran oil in production of zero trans fat containing shortening.

6.6 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 [67,68,69]. 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

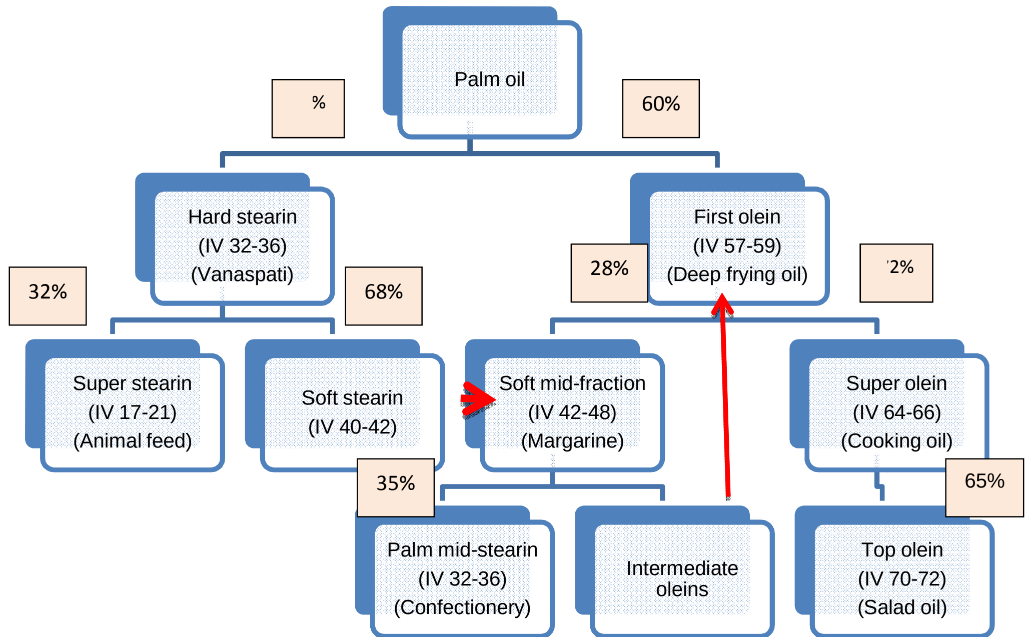


Fig. 2. Fractionation of palm oil in different fractions

products containing both low-TFA's content and low-SFA's [69]. 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 [2,3]. 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) [70], 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 [71]. As per the descriptive sensory profile of soyabean oil reported by [72] it has hazy appearance, lard aftertaste, gluey aroma, yeasty aroma by mouth, pasty and umami taste were higher as compared to Plenish soybean oil.

7. 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.

8. 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 (Fig. 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% [43]. 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.

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

Fig. 3. Nutrition labelling of TFA contaning food products

9. 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.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Menaa F, Menaa A, Menaa B, Treton J. Trans-fatty acids, dangerous bonds for health? A background review paper of their use, consumption, health implications and regulation in France. European Journal of Nutrition. 2012;52(4):1289-1302.
2. Menaa F, Menaa A, Treton J, Menaa B. Technological approaches to minimize industrial trans fatty acids in foods. Journal of Food Science. 2013;78(3):R377-R386.
3. Kodali DR. Trans fats replacement solutions. AOCS Press Urbana, Illinois; 2014.
4. Martin C, Milinsk M, Visentainer J, Matsushita M, de-Souza N. Trans fatty acid-forming processes in foods: A review. Anais Da Academia Brasileira De CiÃncias. 2007;79(2):343-350.
5. Downs S, Thow A, Leeder S. The effectiveness of policies for reducing dietary trans fat: A systematic review of the evidence. Bulletin: World Health Organization. 2013;91(4):262-269H.
6. Eckel R, Borra S, Lichtenstein A, Yin-Piazza S. Understanding the complexity of trans fatty acid reduction in the American diet: American Heart Association trans fat conference 2006: Report of the trans fat conference planning group. Circulation. 2007;115(16):2231-2246.
7. Dijikstra AJ, Hamilton RJ, Hamm W. Trans fatty acids. Blackwell Publishing; 2008.
8. Park Y. Conjugated linoleic acid (CLA): Good or bad trans fat? Journal of Food Composition and Analysis. 2009;22:S4-S12.
9. Remig V, Franklin B, Margolis S, Kostas G, Nece T, Street J. Trans fats in America: A review of their use, consumption, health implications, and regulation. Journal of American Dietetic Association. 2010;110(4):585-592.
10. Rossell JB. Introduction. In: Rossell JB (ed) Frying: Improvement quality. CRC Press, New York; 2001.
11. Sanibal E, Mancini Filho J. Perfil de Ã¡cidos graxos trans de Ã³leo e gordura hidrogenada de soja no processo de fritura. CiÃªncia E Tecnologia De Alimentos. 2004;24(1):27-31.
12. Romero A, Cuesta C, SÃ¡nchez-Muniz F. Trans fatty acid production in deep fat frying of frozen foods with different oils and frying modalities. Nutrition Research. 2000;20(4):599-608.
13. Tasan M, Demirci M. Trans FA in sunflower oil at different steps of refining. Journal of American Oil Chemical Society. 2003;80(8):825-828.
14. Dixit S, Das M. Fatty acid composition including trans -fatty acids in edible oils and fats: Probable intake in Indian population. Journal of Food Science. 2012;77(10):T188-T199.
15. Kohlmeier L, Simonsen N, Van't Veer P, et al. Adipose tissue trans fatty acids and breast cancer in the European community multicenter study on antioxidants, myocardial infarction, and breast cancer. Cancer Epidemiology Biomarkers Prevention. 1997;6(9):705–710.
16. Yli-Jama P, Meyer H, Ringstad J, Pedersen J. Serum free fatty acid pattern and risk of myocardial infarction: A case-control study. Journal of International Medicine. 2002;251(1):19-28.
17. Slattery M, Benson J, Ma K, Schaffer D, Potter J. Trans-fatty acids and colon cancer. Nutrition and Cancer. 2001;39(2): 170-175.
18. Ghafoorunissa G. Role of trans fatty acids in health and challenges to their reduction in Indian foods. Asia Pacific Journal of Clinical Nutrition. 2008;17:212–215.
19. Kavanagh K, Jones K, Sawyer J, Kelley K, Carr J, Wagner J, Rudel L. Trans fat diet induces abdominal obesity and changes in

insulin sensitivity in monkeys. Obesity Research. 2007;15:1675-1684.
20. Willett WC, Stampfer MJ, Manson JE, Colditz GA, Speizer FE, Rosner BA, Sampson LA, Hennekens CH. Intake of trans fatty acids and risk of coronary heart disease among women. Lancet. 1993;341:581–585.
21. Park Y, Pariza M. Mechanisms of body fat modulation by conjugated linoleic acid (CLA). Food Research International. 2007;40(3):311-323.
22. Mozaffarian D, Aro A, Willett W. Health effects of trans-fatty acids: Experimental and observational evidence. European Journal of Clinical Nutrition. 2009;63:S5-S21.
23. Mozaffarian D, Clarke R. Quantitative effects on cardiovascular risk factors and coronary heart disease risk of replacing partially hydrogenated vegetable oils with other fats and oils. European Journal of Clinical Nutrition. 2009;63:S22-S33.
24. Gupta R, Misra A, Pais P, Rastogi P, Gupta VP. Correlation of regional cardiovascular disease mortality in India with lifestyle and Nutritional factors. International Journal of Cardiology. 2006;108:291-300.
25. Kala AL. Cis-, trans- and saturated fatty acids in selected hydrogenated and refined vegetable oils in the Indian market. Journal of American Oil Chemical Society. 2012;89:1813-1821.
26. Huang Z, Wang B, Pace R, Oh J. Trans fatty acid content of selected foods in an African-American community. Journal of Food Science. 2006;71(6):C322-C327.
27. Kuhnt K, Baehr M, Rohrer C, Jahreis G. Trans fatty acid isomers and the trans-9/trans-11 index in fat containing foods. European Journal of Lipid Science and Technology. 2011;113(10):1281-1292.
28. Kroustallaki P, Tsimpinos G, Vardavas C, Kafatos A. Fatty acid composition of Greek margarines and their change in fatty acid content over the past decades. International Journal of Food Science and Nutrition. 2011;62(7):685-691.
29. Meremae K, Roasto M, Kuusik S, Ots M, Henno M. Trans fatty acid contents in selected dietary fats in the estonian market. Journal of Food Science. 2012;77(8):T163-T168.
30. Cakmak Y, Guler G, Yigit S, Caglav G, Aktumsek A. Fatty acid composition and trans fatty acids in crisps and cakes in Turkey's markets. International Journal of Food Properties. 2011;14(4):822-829.
31. Albuquerque T, Sanches-Silva A, Santos L, Costa H. An update on potato crisps contents of moisture, fat, salt and fatty acids (including trans -fatty acids) with special emphasis on new oils/fats used for frying. International Journal of Food Science and Nutrition. 2011;63(6):713-717.
32. Frost, Sullivon. Trans fat consumption trends in India: A strategic insight; The vanaspati manufacturers association of India and Indian vanaspati producers association: New Delhi; 2009.
33. List GR, Warner EK, Pintauro EP, Gil EM, Amer J. Low-trans shortening and spread fats produced by electrochemical hydrogenation. Journal of American Oil Chemical Society. 2007;84:497–501.
34. Zetzl A, Marangoni A, Barbut S. Mechanical properties of ethylcellulose oleogels and their potential for saturated fat reduction in frankfurters. Food and Function. 2012;3(3):327.
35. Patel A, Cludts N, Sintang M, Lesaffer A, Dewettinck K. Edible oleogels based on water soluble food polymers: Preparation, characterization and potential application. Food Functional. 2014;5(11):2833-2841.
36. Patel A, Schatteman D, De Vos W, Lesaffer A, Dewettinck K. Preparation and rheological characterization of shellac oleogels and oleogel-based emulsions. Journal of Colloid Interface Science. 2013;411:114-121.
37. Hughes E, Marangoni AG, Wright AJ, Rogers MA, Rush JWE. Trends in Food Science and Technology. 2009;20:11.
38. Hwang H, Singh M, Bakota E, Winkler-Moser J, Kim S, Liu S. Margarine from organogels of plant wax and soybean oil. Journal of American Oil Chemical Society. 2013;90(11):1705-1712.
39. Botega DCJ, Marangoni AG, Smith AK, Goff HD. The potential application of rice bran wax oleogel to replace solid fat and enhance unsaturated fat content in ice cream. Journal of Food Science. 2013;78(9):1334-1339.
40. Costales-RodrÃguez R, Gibon V, VerhÃ© R, De Greyt W. Chemical and enzymatic interesterification of a blend of palm stearin: Soybean oil for low trans-margarine formulation. American Oil Chemical Society. 2009;86(7):681-697.
41. Adhikari P, Zhu XM, Gautam A, Shin J, Hua JN, Jeung et al. Scaled-up production

of zero-trans margarine fat using pine Nutr oil and palm stearin. Food Chemistry. 2010;119:1332–1338.

42. Mayamol P, Samuel T, Balachandran C, Sundaresan A, Arumughan C. Zero-trans shortening using palm stearin and rice bran oil. Journal of American Oil Chemical Society. 2004;81(4):407-413.
43. Dhaka V, Gulia N, Ahlawat KS, Khatkar BS. Trans fats-sources, health risks and alternative approach - A review. Journal of Food Science and Technology. 2011; 48(5):534-541.
44. L'Abbe M, Stender S, Skeaff C, Tavella M. Approaches to removing trans fats from the food supply in industrialized and developing countries. European Journal of Clinical Nutrition. 2009;63:S50-S67.
45. Jang E, Jung M, Min D. Hydrogenation for low trans and high conjugated fatty acids. Comprehensive Reviews in Food Science and Food Safety. 2005;4(1):22-30.
46. Minihane A, Harland J. Impact of oil used by the frying industry on population fat intake. Critical Review of Food Science and Nutrition. 2007;47(3):287-297.
47. Skeaff CM. Feasibility of recommending certain replacement or alternative fats. European Journal of Clinical Nutrition. 2009;63:S34-S49.
48. King JW, Holliday RL, List GR, Snyder JM. Hydrogenation of vegetable oils using mixtures of supercritical carbon dioxide and hydrogen. Journal of American Oil Chmist Society. 2001;78:107-113.
49. Wright AJ, Wong A, Diosady LL. Ni catalyst promotion of a Cis-selective Pd catalyst for canola oil hydrogenation. Food Research International. 2003;36:1069-1072.
50. Bot A, Veldhuizen Y, den Adel R, Roijers E. Non-TAG structuring of edible oils and emulsions. Food Hydrocolloids. 2009; 23(4):1184-1189.
51. Rønne TH, Pedersen LS, Xu X. Triglyceride selectivity of immobilized thermomyces lanuginosa lipase in interesterification. Journal of American Oil Chemical Society. 2005;82:737–743.
52. Noor Lida H, Sundram K, Siew W, Aminah A, Mamot S. TAG composition and solid fat content of palm oil, sunflower oil, and palm kernel olein belends before and after chemical interesterification. Journal American Oil Chemical Society. 2002;79(11):1137-1144.
53. Norizzah A, Chong C, Cheow C, Zaliha O. Effects of chemical interesterification on physicochemical properties of palm stearin and palm kernel olein blends. Food Chemistry. 2004;86(2):229-235.
54. Zhang H, Jacobsen C, Pedersen L, Christensen M, Adler-Nissen J. Storage stability of margarines produced from enzymatically interesterified fats compared to those prepared by conventional methods chemical properties. European Journal of Lipid Science and Technology. 2006;108(3):227-238.
55. Zhang H, Pedersen L, Kristensen D, Adler-Nissen J, Christian Holm H. Modification of margarine fats by enzymatic interesterification: Evaluation of a solid-fat-content-based exponential model with two groups of oil blends. American Oil Chemical Society. 2004;81(7):653-658.
56. Rønne TH, Yang T, Mu H, Jacobsen C, Xu X. Enzymatic interesterification of butterfat with rapeseed oil in a continuous packed bed reactor. Journal of Agricultural and Food Chemistry. 2005a;53:5617–5624.
57. Lai O, Ghazali H, Chong C. Effect of enzymatic transesterification on the melting points of palm stearin-sunflower oil mixtures. Journal of American Oil Chemical Society. 1998;75(7):881-886.
58. Chu B, Ghazali H, Lai O, Che Man Y, Yusof S, Tee S, Yusoff M. Comparison of lipase-transesterified blend with some commercial solid frying shortenings in Malaysia. Journal of American Oil Chemical Society. 2001;78(12):1213-1219.
59. Osorio NM, Gusma˜o JH, Da Fonseca MM, Ferreira-Dias S. Lipase-catalysed interesterification of palm stearin with soybean oil in a continuous fluidised-bed reactor. European Journal of Lipid Science and Technology. 2005;107:455–463.
60. Zhang H, Xu X, Nilsson J, Mu H, Adler-Nissen J, Høy CE. Production of margarine fats by enzymatic interesterification with silica-granulated thermomyces lanuginosa lipase in a large-scale study. Journal of American Oil Chemical Society. 2001;78: 57–64.
61. Chang T, Lai X, Zhang H, SÃ¸ndergaard I, Xu X. Monitoring lipase-catalyzed interesterification for bulky fat modification with FTIR/NIR spectroscopy. Journal of Agricultural and Food Chemistry. 2005;53(26):9841-9847.
62. van Duijn G, Dumelin EE, Trautwein EA. Virtually trans free oils and modified fats.

In: Williams C, Buttriss J (ed) Improving the fat content of foods. Woodhead Publishing, Cambridge. 2006;490–507.
63. Lida H, Ali A. Physico-chemical characteristics of palm-based oil blends for the production of reduced fat spreads. Journal of American Oil Chemical Society. 1998;75(11):1625-1631.
64. Sundram K, Karupaiah T, Hayes K. Stearic acid-rich interesterified fat and trans-rich fat raise the LDL/HDL ratio and plasma glucose relative to palm olein in humans. Nutrition Metabolism. 2007;4:3.
65. Jeyarani T, Yella Reddy S. Preparation of plastic fats with zero trans FA from palm oil. Journal of American Oil Chemical Society. 2003;80(11):1107-1113.
66. Berger K, Idris N. Formulation of zero-trans acid shortenings and margarines and other food fats with products of the oil palm. Journal of American Oil Chemical Society. 2005;82(11):775-782.
67. Napier J, Graham I. Tailoring plant lipid composition: Designer oilseeds come of age. Current Opinion in Plant Biology. 2010;13(3):329-336.
68. Wilson RF, Hildebrand DF. Engineering status, challenges and advantages of oil crops. In: Mascia PN, Scheffran J, Widholm JM (ed). Plant biotechnology for sustainable production of energy and co-products. Springer-Verlag, Berlin. 2010;209–259.
69. Wilson R. The role of genomics and biotechnology in achieving global food security for high-oleic vegetable oil. Journal of Oleo Science. 2012;61(7):357-367.
70. Sebastian SA, Feng L, Kuhlman LC. Accelerated yield technology TM: A platform for marker-assisted-selection of simple and complex traits. In: Wilson RF (ed) Designing soybeans for 21st century markets. Urbana: American Oil Chemical Society. 2012;287-295.
71. Ulmasov T, Voelker T, Wilkes R, Cornelius J. High-oleic, low-saturate soybeans offer a sustainable and nutritionally enhanced solution for food applications requiring high oils stability. In: Wilson RF (ed). Designing soybeans for 21st century markets. Urbana: American Oil Chemical Society. 2012;267–286.
72. Talbot G. Specialty oils and fats in food and nutrition, properties, processing and applications. Woodhead Publication Series in Food Science, Technology and Nutrition; 2014.

Peer-review history:
The peer review history for this paper can be accessed here:
http://sciencedomain.org/review-history/18937