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Replacements for Trans Fats—Will There Be an Oil Shortage?

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Abstract

Manufacturers use the process of hydrogenation to create trans fats in order to increase the shelf life of baked and fried foods. Ingestion of trans fats is associated with an increased risk of cardiovascular disease. A groundswell of public sentiment is causing regulatory bodies to ban the use of trans fats in foods. Alternatives to trans fats are needed now in order to preserve the freshness and provide an appealing texture of many packaged foods. As trans fats become phased out, there are eight types of approaches currently being developed to substitute for these fats as ingredients for baked and fried foods: (1) modified hydrogenation, (2) genetically modified seeds, (3) interesterification, (4) fractionation and blending, (5) butter and animal fat, (6) natural saturated oils, (7) natural unsaturated oils, and (8) fat substitutes. These alternatives to trans fats will require close scrutiny to ascertain whether they will also turn out to be linked with cardiovascular disease.

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Introduction

Vegetable oils contain a high concentration of unsaturated fatty acids. These fats are prone to oxidation, which produces rancidity. *Trans* fatty acids or trans fats are produced when food manufacturers add hydrogen to unsaturated vegetable oils to saturate or partially saturate their unsaturated bonds for use in cooking, frying, or baking. This hydrogenation process increases the stability, resistance to oxidation, and shelf life of vegetable oils. In addition, hydrogenation raises the melting point of unsaturated vegetable oils, which are liquid at room temperature. This process hardens the oils and converts them into solid or semisolid fats. A solid texture is necessary for the manufacture of shortenings and margarine. Generally, the higher the saturated fatty acid content, the harder a fat will be at room temperature.

The main component of fats and oils is triglycerides, which contain one glycerol molecule and three fatty acid molecules. When these substances are solid at room temperature, then they are called fats, and when they are liquid at room temperature, then they are called oils. This article uses the terms fats and oils interchangeably.

The ingestion of trans fats is associated with heart disease and, for that reason, the use of these substances as food additives is increasingly coming under attack. Trans fats

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Abbreviations: (DAG) diacylglycerides, (FDA) Food and Drug Administration, (HDL) high-density lipoprotein, (LDL) low-density lipoprotein

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are being removed from many widely sold foods and are becoming banned from use in restaurants in many communities. These oils have served a function in the food manufacturing and preparation industries and will need to be replaced by other types of oils. This article reviews the structure and function of trans fats and discusses their potential replacement.

Dietary Fats

The major types of fats in the diet are saturated, polyunsaturated, monounsaturated, and *trans* fats. While unsaturated fats (monounsaturated and polyunsaturated) are beneficial when consumed in moderation, saturated and trans fats may not be. Intervention studies have demonstrated that trans fats raise low-density lipoprotein (LDL) cholesterol levels, lower high-density lipoprotein (HDL) cholesterol levels,[1] and raise lipoprotein(a) levels.[2] Trans fat intake has been positively related to plasma biomarkers of inflammation and endothelial dysfunction, including C-reactive protein, soluble tumor necrosis factor receptor 2, E-selectin, and soluble cell adhesion molecules (soluble intercellular adhesion molecule-1 and soluble vascular cell adhesion molecule-1[3]) . All these effects on risk factors with trans fat ingestion are associated with an increased risk of coronary artery disease.[4] The positive relation between trans fat intake and cardiovascular risk is greater than would be predicted solely from an adverse effect on lipids,[5] which suggests that an adverse effect on endothelial function might account for this additional risk. An additional health risk from ingestion of trans fats is decreased fertility.[6]

Saturated Fats

Saturated fatty acids contain the maximum number of hydrogen atoms that the chain of carbon atoms can hold **(Figure 1).** Saturated fats are usually solid at room temperature. They are inert and do not combine readily with oxygen to become rancid. Saturated fatty acids are found in animal fats and in coconut oil, palm oil, and cocoa butter.

Monounsaturated Fats

Monounsaturated fatty acids contain a single unsaturated or double bond. They lack two hydrogen atoms. Monounsaturated oils usually are liquid at room temperature but solidify at refrigerator temperatures. Monounsaturated fatty acids can help decrease LDL cholesterol when substituted for saturated fats in the diet. Monounsaturated fatty acids are found in canola oil, olive oil, peanut oil, nuts, and avocados.

Polyunsaturated Fats

Polyunsaturated fatty acids contain more than one unsaturated or double bond and are liquid both at room temperature and in the refrigerator. They may combine with ambient oxygen and become rancid. Polyunsaturated fatty acids can help lower LDL cholesterol when substituted for saturated fats in the diet. These fatty acids are found in safflower oil, corn oil, sunflower oil, soybean oil, fatty fish (such as salmon, mackerel, smelt, herring, and trout), walnuts, and seeds.

Trans Fats

Trans fats are a type of fat that is formed when liquid oils are converted into solid fats (such as shortening and hard margarine) through partial hydrogenation of their unsaturated fatty acids. In this process hydrogen is added to polyunsaturated oil to fill some but not all of the unsaturated bonds. Trans fats are found in foods containing partially hydrogenated oils or cooked in such oils.

In trans fats the two hydrogen atoms are on opposite sides of an unsaturated double bond, as opposed to cis fats in which the two hydrogen atoms are on the same side of the double bond. The *trans* configuration results in a straight shape, whereas the *cis* configuration is bent (**Figures 2 and 3**). Compared to *cis* fatty acids, *trans* fatty acids molecules can pack closer together and are less fluid. Thus, trans fats, compared to cis fats, have a higher melting point. This property results in trans fats assuming a solid state rather than a liquid state at room temperature. Trans fats are incorporated into endothelial cell membranes and thus can alter cellular and macromolecular components acting at the interface of the blood vessel wall. These alterations could result in changes in the antihemostatic properties, altered vascular tone, hyperadhesiveness to blood leukocytes, and increased cytokine and growth factor production, all of which are characteristics of endothelial dysfunction.[7]

During hydrogenation of monounsaturated and polyunsaturated fatty acids in vegetable and fish oils, far more *trans* than *cis* double bonds are formed. Furthermore, during hydrogenation of unsaturated fatty acids, *cis* bonds may be converted into *trans* bonds.

Sources of Trans Fats

Almost all edible fats from plants contain unsaturated fatty acids in the *cis* conformation. Trans fats are found naturally in low levels in meat and dairy products because of bacterial hydrogenation of *cis*-unsaturated fatty acids

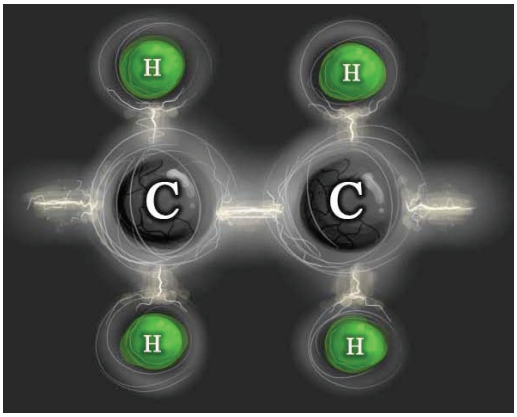

Figure 1. Saturated carbon atoms, each with two hydrogen atoms, joined by a single bond.

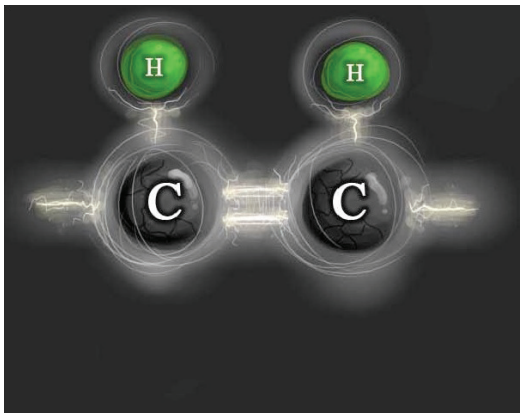

Figure 2. Unsaturated carbon atoms, each with one hydrogen atom, joined by a double bond in the *cis* configuration.

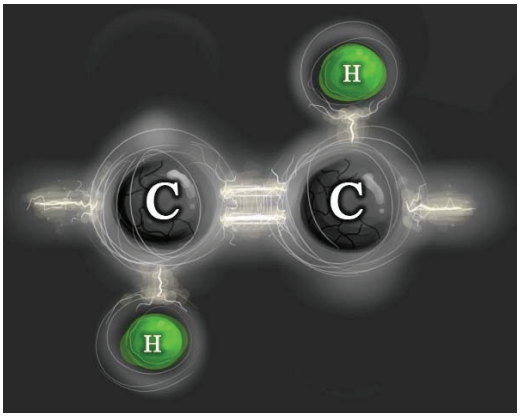

Figure 3. Unsaturated carbon atoms, each with one hydrogen atom, joined by a double bond in the *trans* configuration.

in the stomachs of ruminant animals. However, the major source of trans fats in the diet is foods containing industrially modified and partially hydrogenated vegetable oils.[8]

As food ingredients, partially hydrogenated oils, compared to naturally unsaturated oils, decrease food spoilage. As a frying medium, however, unsaturated oils tend to become foamy, smoky, or dark colored after prolonged use. Restaurants may prefer to fry with partially or fully saturated fats because these fats need not be changed as frequently.[9] Food manufacturers may also prefer to use saturated fats rather than unsaturated fats in baked goods, candies, or processed snack foods that require margarines, spreads, or shortenings. Saturated oils in these foods will contribute to a desirably soft texture, volume, aeration, and feel of such foods at room temperature.

Most of the trans fat in a typical American diet comes from commercially fried and baked foods made with vegetable shortening, hard margarines, and oils containing partially hydrogenated oils and fats. According to U.S. data reported by the Food and Drug Administration (FDA) in 2003, products containing partially hydrogenated oils constitute the major source of trans fat intake (79.4%). The main contributors to total trans fat intake include margarine (16.56%), cakes and related products (23.82%), cookies and crackers (9.78%), fried potatoes (8.32%), chips and snacks (4.81%), and household shortening (4.28%). Animal products supply the remaining 20.6% of dietary trans fat.[10]

Regulation of Trans Fats

As of January 1, 2006, the FDA has required manufacturers of conventional foods and some dietary supplements to list trans fat on their nutrition labels. Manufacturers of dietary supplements (e.g., energy and nutrition bars) must also list trans fat on the Supplement Facts panel when their products contain reportable amounts (0.5 gram) of trans fat. The FDA has estimated that by 2009, the beneficial effects of this labeling rule (entitled "Trans Fatty Acids in Nutrition, Labeling, Nutrient Content Claims, and Health Claims") will result in a 0.1% decrease in total trans fat intake by adults. In the U.S. population, such a decrease in trans fat intake would be estimated to lead to a fall in serum LDL cholesterol (a risk factor for myocardial infarction) as a consequence of the expected dietary modifications from this ruling. The FDA calculated that the beneficial lipid effect would result in a gain of 1920–3840 discounted life years annually in the United States.

The FDA further estimated, by including avoidance of both fatal and nonfatal events, that this ruling will provide an annual savings to the U.S. economy of between $991 million and $2.284 billion.[10]

Tiburon, California became America's first city to ban trans fats from restaurants in 2004. New York City became America's first major metropolis to ban trans fats from restaurants in December 2006. Restaurants in that city will be barred from using most frying oils containing artificial trans fats by July 2007 and will have to eliminate artificial trans fats from all of their foods by July 2008. In 2003 Denmark became the first country to introduce laws limiting the amount of trans fat in processed foods.[11] Many countries and other U.S. cities are currently considering similar bans.

In March 2007, the California State Assembly Health Committee approved legislation that would ban the use of trans fats in oils, margarine, and shortening at "food facilities," including restaurants, cafeterias, and other businesses. The measure would not apply to packaged food sold in either grocery stores or restaurants. If this bill becomes law, then California would be the first state in the United States to ban the use of trans fats.

Alternatives

Several factors have limited the introduction of alternatives to trans fats into the marketplace: (1) performance, (2) availability, (3) economics, and (4) safety. Replacement products for trans fats must be able to provide at least the same functional characteristics of the materials they replace. Partial hydrogenation allows creation of many engineered saturated or partially saturated oils with specific characteristics for use by the food industry. No alternate method for creating a wide range of fats for frying and storage of baked products has thus far been developed. The use of trans fat alternatives in major consumer products, such as fast foods, requires a large supply. New candidate oil products are not yet commercially available on a significant scale because of a lack of adequate acreage for growing new seed crops. These oil products could become widely available within a few years, however, if the food industry is committed to their use. The increased costs of developing and producing trans fat alternatives will be passed on to consumers of foods containing these products. The safety of any alternative to trans fats must be studied so that consumers are not simply ingesting an alternate form of saturated fat that will be just as dangerous as natural saturated fats or as trans fats.

The food industry is in the process of searching for alternative oils to trans fats that can provide good flavor, deliver good performance, and be purchased at a good price.[12] Much research is currently being conducted to develop new, healthier fats and oils for food production. Vegetable oils have only limited applications in food products when they are used in their native form. They must therefore be modified chemically, physically, or genetically in order to change their properties. When products containing partially hydrogenated fats or oils are reformulated to lower the trans fat content, functionality may require the reformulated products to have more saturated fat than the original product.

Partially hydrogenated oils were introduced into the U.S. food supply in 1911 when Procter and Gamble launched Crisco shortening, made of partially hydrogenated cottonseed oil. On January 24, 2007, Crisco was reformulated to eliminate trans fats by J.M. Smucker Co., which acquired this product in 2002. This reformulation reflects a widespread trend in the food industry to remove hydrogenated vegetable oils from cooking spreads[13] such as shortening (which is a pure fat product that is solid at room temperature often because of a high concentration of hydrogenated trans fats) and margarine (which is a water-in-oil emulsion made from vegetable or animal oils that may contain high concentrations of hydrogenated trans fats as hardening agents). Butter is not affected by this trend because this spread is made from butterfat, an ingredient in cream, and contains mostly naturally saturated fat and no hydrogenated fats. As trans fats become phased out, there are currently eight types of approaches being developed to substitute for these fats as ingredients for baked and fried foods. These approaches are listed next.

Modified Hydrogenation

Full hydrogenation of vegetable oils would produce exclusively saturated fatty acids that are too waxy and solid to use in food production. Consequently, the partial hydrogenation process used by the industry is not intended to eliminate all the double bonds. Partially hydrogenated oils increase the shelf life and flavor stability of foods, as well as modify some of the saturated fatty acids that can oxidize and become rancid. Processes under development can generate hydrogenated oils containing less than half the level of trans fat produced under traditional hydrogenation conditions. The standard hydrogenization process can be modified by altering the type of catalyst, the time of the reaction, or the temperature and pressure of the process.[14–16] This hydrogenation approach would be expensive on a commercial scale.

Genetically Modified Seeds

Plant seeds can be developed through breeding or genetic engineering to be sources of modified oils.[17] This approach can reduce or eliminate the concentrations of polyunsaturated oils, such as linoleic acid and linoleic acid (containing two double bonds and three double bonds, respectively), that are most responsible for spoiling[18] Selective breeding programs have created soybean seeds and sunflower seeds with very low levels of unsaturated oils.[19] Low unsaturated fat oils are more stable than natural oils made from regular seeds. Plant breeding or genetic engineering can also be used to increase the saturated fat content of seeds to improve stability. High-stearic (saturated fat) and high-oleic (a monounsaturated fat) cottonseed oils are being developed to contain desirable mixes of saturated and unsaturated fats that will be stable in food preparation.[20] These modified plants will produce oils that are more saturated and stable overall than natural oils, but not overly saturated or waxy where they would not melt properly in cooking. These plant oils with greater saturation than their corresponding natural oils are not industrially hydrogenated and they are virtually free of trans fats. This technology is expensive and not yet widely adopted to produce sufficient supplies of virtually trans-free oils. Consumers of these products will need to obtain essential dietary unsaturated fatty acids from other sources.

Interesterification

Interesterification of vegetable oils is currently a widely adopted modification technique for hardening triglycerides contained in unsaturated vegetable oils.[21] Interesterification is a chemical reaction that redistributes fatty acids on the glycerol backbone of a triglyceride molecule by blending fatty acids from more than one type of triglyceride. The rearrangement does not change the composition of any of the fatty acids from the starting materials, and because hydrogenation is not involved, trans fats do not form during this process. Unsaturated vegetable oils are blended with highly saturated oils under specific conditions. New nonnatural combinations of triglycerides with specific melting profiles and functional attributes are formed that are intermediate in hardness between natural unsaturated oils and fully saturated oils. The treated vegetable oils essentially become hardened when the glycerol backbones of these initially unsaturated fats become esterified by saturated fats. This type of chemical reaction can be controlled by sequentially running it below target melting points to initially precipitate the hardest most saturated oils and leave the desired less saturated oils in a liquid form. Later the intended final interesterified end products, which are intended for the food industry, can be isolated.

In a study of lipid levels following ingestion of margarines containing either *trans* fatty acids or interesterified unsaturated non-*trans* fatty acids, interesterified fat use resulted in significantly lower total and LDL cholesterol levels.[22] In another diet study,[23] a natural saturated fat was compared to two forms of modified replacement fats, one containing *trans* fatty acids and the other containing interesterified unsaturated non-*trans* fatty acids. The effect on circulating lipids with both modified oils was similar, namely significant increases in the total cholesterol/HDL cholesterol and LDL cholesterol/HDL cholesterol ratios and significant decreases in HDL cholesterol levels.[23] However, ingestion of the two modified oils also resulted in increased plasma glucose and decreased plasma insulin levels, and these effects were both significantly more pronounced with interesterified fat than trans fat. Other previous studies of trans fat intake on glucose metabolism have (1) demonstrated no effect in glycemia in healthy controls[24] and subjects with type 2 diabetes[25] and (2) demonstrated postprandial insulin hypersecretion in type 2 diabetes subjects.[25] The potential greater adverse effect of interesterified fats, compared to trans fats, on glucose and insulin levels merits further study.

The long-term risks of ingesting interesterified fats are unknown. Substitution of native butter with butter containing interesterified unsaturated non-*trans* fatty acids has resulted in no effect on lipemia,[26] in a significant reduction of LDL cholesterol levels,[27] or in an elevation of triglyceride levels[28] in three studies. The literature appears to demonstrate no consistent adverse lipid effect from using interesterified unsaturated fatty acids compared to trans fats as hardening agents in spreads.

An application of interesterification is being developed to create triglycerides with fatty acid combinations not typically found in nature, such as reduced calorie mixtures of short and long chain triglycerides[29] or even diacylglycerides (DAG) containing only two fatty acid chains.[30] It has been reported that human subjects with impaired glucose tolerance[31] and type 2 diabetes[32] had smaller postprandial rises in serum triglycerides following a meal prepared with DAG than with triglycerides. Medium chain fatty acids have also been used in interesterified triglycerides. These oils are intended to provide both functional and health benefits.

The intersesterification approach using natural fatty acids as hardening ingredients is costly and might not outperform trans fats in its metabolic effects.

Fractionation and Blending

Fractionation involves separating oils into their different components, which are characterized by different physical properties. Natural components of vegetable oils are low in trans fats and can be combined into various combinations.[33] Each particular blended combination can be tailored to the requirements of a food in terms of required cooking and taste properties according to the overall characteristics of the blend.[34] This fractionation approach is costly and involves much testing to create optimal combinations of natural ingredients. A method for blending mix oil, water, and monoglycerides to form a multilamellar crystalline gel substance may provide the same structural and functional properties as trans and saturated fats.[21]

Butter and Animal Fat

An option for replacing trans fats is a return to butter, lard, and tallow as fat additives because these substances are very low in trans fats. However, these substances are high in saturated fat and cholesterol and extremely atherogenic.[35] This approach of using animal fats to create good-tasting foods is not viable because of the adverse metabolic effects of this type of lipid.

Natural Saturated Oils

Solid vegetable oils were widely used in prepared food until the late 1980s when food companies mostly replaced them with hydrogenated oils made from soy, corn, and sunflower oils. While they are less harmful than fats high in trans fats, they are possibly still more conducive to heart disease than vegetable oils rich in mono- and polyunsaturated fats. Reports claiming[36] and disputing[37] a link between ingestion of natural saturated palm oils and heart disease have been published in recent years. At this point, the overall benefit or risk of palm oils is not established. These fats are probably a better choice than trans fats, for the food industry, but cardiovascular risk is probably reduced most effectively when *trans* fatty acids and saturated fatty acids are both replaced with *cis*-unsaturated fatty acids.[38, 39] The approach of using solid vegetable oils as food additives is not attractive because of the suspected link between ingestion of these substances and cardiovascular disease.

Natural Unsaturated Oils

One of the healthiest alternatives to using saturated or partially hydrogenated fats is the use of natural unsaturated liquid vegetable oils such as olive, canola, corn, or soy oils. This approach of utilizing unsaturated fats would lead to more rancidity and greater spoilage than is the case with partially or fully hydrogenated or naturally saturated oils.[40] Foods containing unsaturated oils would not have a long shelf life.

Fat Substitutes

Some companies are replacing partially hydrogenated oils with nonfatty texture-building substances, such as plant fiber or whole oats.[41] In foods, these substances feel and taste like fat.[42] Another trans fat-free technology combines emulsifiers with unhydrogenated unsaturated oil to mimic the performance of shortening. These products, when mixed with unhydrogenated oils, enable food companies to claim "zero trans fats" or "no hydrogenation" on food labels.[43] A microsaturation process that combines unsaturated oils with saturated medium chain triglycerides in a heated and agitated blender has been claimed to produce a dense mixture of fats that fold into each other and could serve as a replacement for saturated or hydrogenated vegetable oils.[44]

Future Trends

There is a growing movement in the United States and other countries to ban the use of trans fats. At some point, viable substitutes for these oils will become established by way of one or more technologies that will have the necessary performance, availability, and cost. Because of the requirements for oils with specific properties by the food industry that uses them in frying and baking, a trans fat substitute will need to be closely related in structure to currently available saturated fats that are already known to be risk factors for heart disease. After trans fats are phased out and the food industry replaces them with new saturated or partly saturated fats, the medical community will need to study the next generation of frying and baking oils closely to evaluate their safety. At this time and possibly in the future as well, the best way to avoid trans fats and potentially unhealthy substitutes for trans fats is to minimize the intake of fried foods, packaged baked goods, and snacks.

Acknowledgements:

Figures courtesy of Anna Klonoff.

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