Path to Phasing out Industrially-Produced Trans Fats

from Bakery and Confectionery Foods

Bakery and Confectionery Manufacturers Guide for iTFA Replacement

ifba
INTERNATIONAL FOOD & BEVERAGE ALLIANCE

AOCS Since 1909
Your Global Fats and Oils Connection

About IFBA

The International Food & Beverage Alliance (IFBA) is a group of twelve global food and non-alcoholic beverage companies - The Coca-Cola Company, Danone, Ferrero, General Mills, Grupo Bimbo, Kellogg, Mars, Mondelēz International, Nestlé, PepsiCo and Unilever - that share a common goal of helping people around the world achieve balanced diets, and healthy, active lifestyles. IFBA is a non-commercial, non-profit making organization, in special consultative status with the UN's Economic and Social Committee (ECOSOC).

www.ifballiance.org

Follow us on Twitter and LinkedIn

About AOCS

Founded in 1909, the American Oil Chemists Society (AOCS) is an international scientific society with more than 4,500 members in over 90 countries. AOCS offers a forum for the exchange of ideas, information, and experience among its members and others who have a professional interest in advancing the science and technology of fats, oils, surfactants, detergents, and related materials.

www.aocs.org

Copyright

Copyright © IFBA, April 2022

Table of Contents

Table of Figures

Foreword

Global momentum is growing for the phasing out of industrially produced trans fats (iTFAs) and partially hydrogenated oils (PHOs) from global food systems due to their association with increased risk of coronary heart disease. The World Health Organization (WHO) estimates that each year, intake of iTFAs leads to more than 500,000 deaths from cardiovascular disease globally. In order to protect health and save lives, WHO recommends the elimination of iTFAs to prevent non-communicable diseases, such as coronary heart disease.

In 2019, IFBA members committed to align their global standard with the WHO's recommendation for a maximum iTFA threshold in food products not exceeding 2 grams of iTFA per 100 grams of fat or oil by 2023. Reducing iTFAs in processed foods – especially in baked goods and confectionary products – while maintaining shelf life and appealing appearance, texture and taste can be challenging. There is no one-size fits all solution and each option needs to be applied differently to each food product. As part of their commitment to WHO to phase out iTFAs, IFBA committed to support other businesses in doing the same.

This concrete handbook is a technical document aimed at food manufacturers, big and small, that highlights the challenges of oil replacement and offers solutions, while keeping public health objectives front and centre. Focused on the context of bakery and confectionary foods, this compilation of state-of-the-art research aims to help food manufacturers effectively phase out iTFAs and replace partially hydrogenated oils (PHOs).

This practical guide, which was compiled for IFBA by experts from the American Oil Chemists' Society (AOCS), will help food manufacturers around the world to begin their journey toward iTFA elimination. IFBA would like to express our deep appreciation for the invaluable work of AOCS in composing this handbook. We would also like to recognize the coalition of contributors that made this guide possible, including supplier insight and technical expertise from Cargill, manufacturing guidance from Nestlé, and public health perspectives provided by Resolve to Save Lives.

Scientific background on Trans Fatty Acids

Fats and oils from animal or vegetable origins are important ingredients in food products around the globe. They are a calorie-dense food component (nine kilocalories per gram versus four kilocalories per gram for carbohydrates and proteins) and source of essential fatty acids (polyunsaturated fatty acids). They also play a functional role that gives food products texture, structure, and flavor.

Over the last decades, scientific evidence that industrially produced trans fatty acids (TFA) from partially hydrogenated fats and oils pose a risk of coronary heart disease (CHD) has emerged. Studies indicate that an increased intake of TFA in the diet (>1% of total energy intake) is associated with increased risk of CHD mortality and events. Health officials worldwide advocate reductions in TFA intake. Several countries and regions have introduced new regulations and policy actions (including mandatory and voluntary TFA labelling, reformulation, and national and local TFA prohibitions) that have restricted or eliminated the content of industrially produced TFA in food, thereby reducing TFA intake in their populations.

	> High PUFA oil with antioxidants > High oleic oils, moderate PUFA	> Hardstocks interesterified with high PUFA oils > Hardstocks blended with high PUFA oils	Not available
	> High oleic oils with no/low PUFA	> Hardstocks interesterified with low PUFA oils > Hardstocks blended with low PUFA oils	> Hardstocks interesterified with some PUFA oils > Hardstocks blended with some liquid oils > Hardstocks interesterified with some MUFA oil
POSITIVE HEALTH IMPACT (Lower SFA + more PUFA)	**Not recommended:** > Liquid palm fractions > Animal or tropical fats	**Not recommended:** > Semi-solid palm fractions > Animal or tropical fats	**Not recommended:** > Solid palm fractions > Fully hydrogenated oil > Coconut oil > Palm kernel oil
	LIQUID	**SEMI-SOLID**	**SOLID**

Figure 1 Summary of partially hydrogenated oil (PHO) alternatives by health impact and solid fat functionality

The World Health Organization (WHO) and Trans Fatty Acids

The World Health Organization (WHO) has initiated an action framework (REPLACE) for the elimination of industrially produced TFA from food supplies globally by 2023. REPLACE is a roadmap to help countries reduce and eliminate TFA by replacing them with healthy fats and oils—particularly ones that are lower in saturated fat and higher in (poly) unsaturated fatty acids, wherever possible and feasible.

Industrially produced TFA have no known health benefits, and the fact that several countries have virtually eliminated them from their food supply offers strong evidence that replacement is possible and feasible.

This document is meant to guide bakery and confectionery food manufacturers on their path toward eliminating these harmful fats from the foods they make.

What are Trans Fatty Acids (TFA) and where are they found?

Natural oils and fats are liquids or semisolids consisting primarily of triacylglycerols (TAG), often referred to as triglycerides. TAG contain a glycerol backbone with three linear carboxylic acids called fatty acids. The glycerol portion of TAG is constant in all oils and fats, while the identity and location of fatty acids varies depending on oil variety. A typical TAG chemical structure is shown in Figure 2.

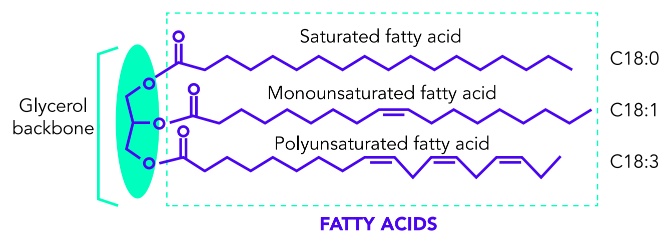


Figure 2 Structure of a typical triacylglycerol showing the glycerol backbone region esterified with three different fatty acids: stearic (C 18:0), oleic (C 18:1), and linolenic (C18:3) acids.
Source: Kodali, D.R. (2014). *Trans Fats Replacement Solutions*, AOCS Press

Fatty acid structures differ in carbon chain length and the number of double bonds. Most naturally occurring fatty acids contain an even number of 4 to 24 carbons.

Saturated fatty acids have no double bonds. The more prevalent saturated fatty acids in oils and fats are lauric (C12), myristic (C14), palmitic (C16), and stearic (C18) acids. The number in parenthesis indicates the number of carbon atoms in the fatty acid chain. Sometimes a zero is added after the number. This means that there are no double bonds in the fatty acid. Unsaturated fatty acids contain one or more double bonds The positions and configurations of double bonds in the chain are very important. The predominant unsaturated fatty acids are oleic (C18:1), linoleic (C18:2) and linolenic (C18:3) acids. The number in the parenthesis after the colon indicates the number of double bonds in the fatty acid. In oleic acid, the double bond is at carbon 9. Linoleic acid has double bonds at carbons 9 and 12, and linolenic acid has them at carbons 9, 12, and 15. Fatty acids containing a single double bond are "monounsaturated", while those with more than one double bond are "polyunsaturated". Although hundreds of different fatty acids occur in oils and fats, the fatty acids referred to above are most common and abundant in natural oils and fats. Vegetable oils contain a mixture of TAG molecules of varying concentrations. Figure 3 lists the fatty acid composition of several conventional vegetable fats and oils.

	S.C.	Lauric	Myristic	Palmitic	Stearic	L.C.	Oleic	Linoleic	Linolenic
Oil Type	C6–10 *	C12	C14	C16	C18	C20–24 †	C18:1	C18:2	C18:3
Soybean	—	—	—	11	4	—	23	55	7
High Oleic Soy	—	—	—	8	5	—	75	9	3
Cottonseed	—	—	1	22	3	—	19	54	1
Sunflower	—	—	—	7	5	—	19	68	1
High Oleic Sunflower	—	—	—	4	5	—	82	9	—
Canola	—	—	—	4	2	—	62	22	10
High Oleic Canola	—	—	—	4	2	2	75	14	3
Olive (Virgin)	—	—	—	9	3	—	80	7	1
Peanut	—	—	—	11	2	7	48	32	—
Corn	—	—	—	11	2	—	28	58	1
Shea Butter	—	—	—	4	42	1	46	7	—
Coconut	15	47	18	9	3	—	6	2	—
Palm kernel	8	48	16	8	2	—	15	3	—
Palm	—	—	1	45	4	—	40	10	—

Figure 3 The fatty acid composition (wt.%) of conventional vegetable fats and oils (Fatty acid compositions of the oils may show differences depending on sourcing regions, seasons, temperature and processing conditions.)

* Short- and medium-chain C6:0 hexanoic (caproic), C8:0 octanoic (caprylic), C10:0 decanoic (capric) fatty acids.
† Long-chain C20:0 eicosanoic (arachidic), C22:0 docosanoic (behenic), C22:1 *cis* C13 docosenoic (erucic), C24:0 tetracosanoic (lignoceric) fatty acids. Kodali, D.R. (2014). *Trans Fats Replacement Solutions*, AOCS Press.

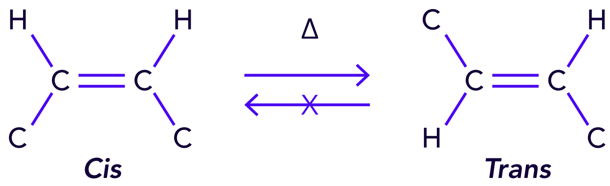


Figure 4 Heat-catalyzed *cis, trans* isomerization of a double bond. The X on the leftward arrow indicates that the isomerization from *trans* to *cis* is energetically unfavorable and thus hardly takes place. **Source:** Kodali, D.R. (2014). *Trans Fats Replacement Solutions*, AOCS Press.

Double bonds in fatty acids occur in two configurations: one with both hydrogen atoms on the same side (*cis*, in Latin), and the other with the hydrogens on opposite sides (*trans*, in Latin, Figure 4). Both "*cis*" and "*trans*" are written in italics to represent the chemical configurations shown in the 2-dimension drawing in Figure 4.

A *cis* double bond is rigid and creates a kink in the carbon chain. With few exceptions, the double bonds in most of the unsaturated fatty acids that occur in natural fats and oils are in the cis configuration.

A *trans* double bond is also rigid but results in a linear carbon chain similar to the structure of saturated fatty acids. More linear chains result in a fat that is solid at lower temperatures, since the chains can pack closely together. More kinked (*cis* unsaturated) chains result in an oil that is liquid at lower temperatures.

There are two basic sources for TFA: those that occur naturally in some animals and those that are produced industrially by hydrogenation. Small amounts of natural TFA are produced by biohydrogenation of unsaturated *cis* fatty acids. For example, bacteria in the rumen of ruminant animals produce several *trans* fatty acids, the most common being vaccenic acid (trans C18:1). Animal-derived TFA are only found in low levels in most diets. The predominant source of dietary TFA in modern diets is produced industrially.

Industrial partial hydrogenation of vegetable oil is done to modify the characteristics of an oil to get a desired structure and melting behavior and/or to improve oxidative stability. It is accomplished industrially using a chemical catalyst. This produces unsaturated fatty acids with a large number of different structures, predominately TFA with 18 carbons, especially elaidic acid (*trans* C18:1(n-9)).

The high temperatures used in the last step of industrially processed oils ensures the oil is safe for consumption but also creates low levels of TFA (1–2%). For most oils it is technically possible to keep these levels under1%. Hence, the majority of TFA from non-natural sources in food products are from intentional partial hydrogenation of oils and fats, as opposed to trace amounts from nonhydrogenated oils.

When present in a country's food supply, industrial TFA arising from partial hydrogenation is the major source of dietary TFA, contributing much more than the natural occurring TFA from animal origin (animal fats, butter, ghee, and milk). Figure 5 lists the more common sources of TFA in the diet.

Source	Amount (wt %)
Refined oils (RBD)	0.5–2
Tallow	5–6
Butter	3–6
Partially hydrogenated vegetable oils (PHVO)	5–45

Figure 5 Common sources of TFA from all sources found in food products
Source: Kodali, D.R. (2014). Trans Fats Replacement Solutions, AOCS Press.

What are Partially Hydrogenated Oils (PHO) and where are they found?

Hydrogenation is a process that converts liquid oils to semisolid fats, which are more suitable than liquid oils for shortenings and margarines. The process consists of reacting liquid oil with hydrogen gas in the presence of a catalyst under conditions. The hydrogen reacts with the *cis* double bonds of the fatty acids and converts them to saturated bonds or *trans* bonds.

Because the melting point of both saturated fatty acids and TFA are higher than the melting point of the unsaturated fatty acids of the same chain length, this process raises the melting point of the fat by increasing the level of solid fat in the oil. The degree of melting point increase corresponds to the degree of hydrogenation.

For reference, Figure 6 shows space-filling models of a saturated 18-carbon fatty acid (stearic acid); a monounsaturated 18-carbon fatty acid in the *trans* configuration (elaidic acid) and a monounsaturated 18-carbon fatty acid in the natural cis configuration (oleic acid). Note the associated melting points for each fatty acid.

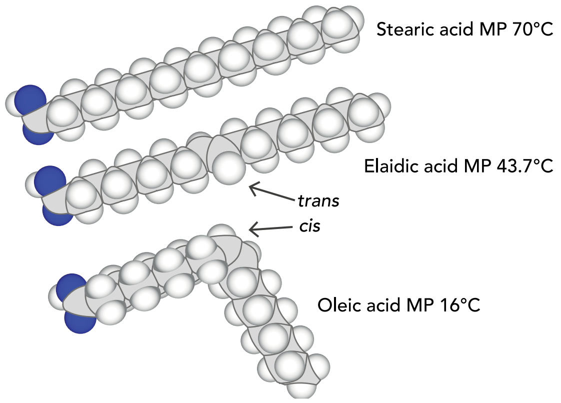


Figure 6 Saturated and unsaturated C18 fatty acids with their respective melting points. **Source:** Kodali, D.R. (2014). *Trans Fats Replacement Solutions*, AOCS Press.

The properties of PHO are governed by the degree of hydrogenation. Stopping the process at intermediate points on the path to full hydrogenation produces PHO with a variety of melting points and solidification. The resulting PHO can be malleable and plastic-like over a desired temperature range.

Partial hydrogenation imparts a solid fat profile that remains uniform and plastic-like during the storage and handling of the solid fat, and at the time a food product is prepared (mixing, proofing, creaming, folding).

When the hydrogenation process is complete, all *cis* and *trans* double bonds are completely hydrogenated, resulting in a fully hydrogenated oil (FHO) consisting of almost only SFA. Fully hydrogenated oils can be too solid and waxy for food applications but can be blended with other fats and oils to get the desired structure and melting behavior. Often the blended oils are the primary replacements for PHO in many countries.

Solid fats are valuable in food applications because, unlike oils, they are resistant to oxidation and have improved texture and sensory attributes. In oxidation, double bonds in unsaturated fatty acids react with molecular oxygen to form hydroperoxides, which in turn break down to create radicals that promote further oxidation. The breakdown products formed during oxidation lead to off-flavors and odors.

The rate of oxidation depends on the number of double bonds in an oil; polyunsaturated fatty acids (PUFA) are sensitive to oxidation, while saturated fatty acids are resistant to oxidation because they lack double bonds. Monounsaturated fatty acids, including *trans* monounsaturated fatty acids, are much more resistant to oxidation than PUFA.

Nonhydrogenated oils high in monounsaturated fatty acids (MUFA) (e.g., high-oleic sunflower oil) are non-TFA and low-SFA alternatives for frying applications.

Solid fat provides functional properties to foods by contributing to their manufacturing process and final structure, texture, and mouthfeel. These properties are very important in food applications such as baked goods, where a certain amount of solid fat is crucial. In baked good applications, solid fats give the dough pliability and can be spread, distributed in layers, or distributed discretely depending upon the product requirement.

Some of the unique properties provided by solid fats in baked goods are tenderness, flakiness, hardness, volume increase, layer separation, air entrapment while baking, dimensional structure, lubricity, and freshness (softness). However, alternatives are available that deliver solid fat functionality while not increasing saturated fat content, e.g. interesterified or blended oils and fats.

In addition to baking and frying applications, PHO is found to a lesser extent in confectionery products, as it is an inexpensive replacement for cocoa butter in chocolate flavored coating and cream centers. Cocoa butter is a specialty fat mainly used to make chocolate. It has a very high solid fat content with ideal melting characteristics (it melts rapidly at body temperature) for confectionery applications. But with its limited availability and very high cost, its use is highly specialized in high-end food applications.

PHO fats with similar solid fat profiles have been widely used to replace cocoa butter at low costs. It is possible to create non-PHO alternatives to cocoa butter at costs that are higher than PHO but lower than cocoa butter.

Summarizing, the melting and solid fat profile of a fat imparts certain desirable properties such as hardness, crispiness, snap, and texture to a food product. These fat functional properties are derived from the solids in the fat and originate naturally (animal fats, tropical oils such as palm, palm kernel, coconut) or by partial hydrogenating oils to make PHO.

How to determine if a fat or oil contains PHO

Determining whether a fat or oil contains PHO is not easy based on appearance, melting point, or solid fat profile. There are two potential ways to determine a fat's composition and whether it contains TFA.

The first, is to ask the fat or oil supplier or manufacturer to supply the level of TFA in the shortening, along with an ingredient statement that lists the oil sources used. The term "partially hydrogenated" before the name of an oil or fat in the ingredient statement (e.g., partially hydrogenated soybean oil or partially hydrogenated cottonseed oil) indicates that the fat or oil contains industrially produced TFA. However, in some countries, labeling rules allow PHOs to be listed as: "hydrogenated oil", "shortening", "vegetable oil", and so on. So, labelling information alone may not be sufficient to determine if PHO is present.

Only "partially hydrogenated" fats or oils contain elevated levels of TFA. "Fully hydrogenated" fats or oils, on the other hand, are fully saturated and therefore contain almost no TFA.

The declared TFA content of a fat by the supplier or manufacturer should be in the range of 1 to 2% for non-ruminant fats of vegetable origin. Ruminant-based fats may contain as much as 6% *trans* fatty acids. In all cases, the allowed TFA content should reflect the composition of the blend: The vegetable portion should not have more than 1–2% TFA, while the ruminant part should not have more than 5–6% TFA. Thus, if a blend of vegetable oil with 10% butterfat has a TFA content of 3.5%, the blend contains PHO.

If the requested information is not available, a second method can be used to determine if a fat or oil contains TFA. Its fatty acid composition (FAC) can be analyzed by gas chromatography (GC) in an analytical lab capable of carrying out American Oil Chemists' Society (AOCS) official method AOCS Ce 1j-07 ("*cis*-, *trans*-, Saturated, Monounsaturated, and Polyunsaturated Fatty Acids in Extracted Fats by Capillary GLC").

This analytical method gives a listing of all fatty acids found in the sample, including all the TFA isomers. These are listed as Fatty acid methyl esters (FAME). The total value of the TFA isomers is the TFA value of that fat or oil.

Non-PHO Fat Options for Replacement of PHO Fats

Replacing a PHO fat with healthier non-PHO fat is feasible and can be cost-effective. From a health perspective, a non-PHO replacement should have as little saturated fat and as much unsaturated fat as possible.

Sometimes, the healthiest alternatives may not provide the desired structure, function, and cost requirements. Preferably, non-PHO replacement fats should not contain more saturated fat than the sum of SFA and TFA in the PHO products. The fats and oils industry has been successful in providing non-PHO fat alternatives worldwide. A non-PHO fat alternative can range from a simple, straightforward substitute with little alteration to the ingredients and preparation of a food to a more complex solution. An adjustment to one or more ingredient levels and/or the food preparation process to obtain the desired finished product match may be required.

A fat is a semisolid or solid at ambient temperature if it contains a significant amount of fatty acids with a high enough melting point. In a PHO fat, the saturated fatty acids and TFA have melting points above ambient and provide the solids profile to the fat. The melting behavior and solids profile of a non-PHO fat are determined by the percentage of saturated fatty acids, but also by the chain lengths of the saturated fats (longer is more solid) and by the distribution of fatty acids within the fat molecule.

The process of interesterification can rearrange the distribution of fatty acids within a fat molecule. Combining interesterification with blending of oils can achieve more solid fat functionality in a food product at lower SFA levels. Interesterification of a liquid oil alone, which only rearranges the existing fatty acids of the liquid oil, does not generally produce a solid fat. Therefore, the solids in non-PHO fats rely largely on the saturated fatty acids of a natural solid fat or a fully hydrogenated fat. Blending and interesterification of oils and solid fats can be used to create fats that deliver a desired fat solids profile at the lowest possible SFA levels.

Other ingredients that exhibit solid or solid-like behavior, such as waxes, phytosterols, and other natural oleogelators that form oleogels, can be incorporated into liquid oils to replace PHO, but these replacements may have limited availability or be costly for commodity food products. Oleogels and other non-triglyceride replacements for PHO are beyond the scope of this paper.

The starting point in identifying a non-PHO fat replacement is to first determine the physical properties of the PHO fat being used in the food item. Analytical testing may include the physical tests listed in Figure 7.

Analytical Testing	AOCS Official Method
Melting Point:	
Capillary Melting Point (CMP)	Cc 1-25
Dropping Point (DP)	Cc 18-80
Solids Profile:	
Solid Fat Content (SFC)	Cd 16b-93
Fat Oxidative Stability:	
Oil Stability Index (OSI)	Cd 12b-92

Figure 7 Suitable analytical tests to characterize the physical properties of a fat.

Once the physical properties of the PHO have been characterized, an empirical match of these properties with the properties of non-PHO fats can be made. Alternatives may need to be evaluated by trial-and-error testing in the application.

The alternative non-PHO fats generally fall into five categories:

1. High MUFA (high-oleic) liquid oils for applications that do not require solid fat functionality, such as frying
2. Naturally solid fats and their blends
3. Fractions of naturally solid fats and their blends
4. Interesterified oils and fats
5. Blends of naturally solid fats, fractions of fats and oils, and/or interesterified oils and fats

High MUFA (high-oleic) liquid oils

Commercially available high-oleic oils (70% oleic acid content) are a non-PHO replacement for applications (e.g. frying) where a solid fat is not required. High-oleic oils contain lower SFA than PHO and many naturally solid fats. They are more resistant to oxidation and have a longer fry life resulting in an extended finished product shelf-life compared to commodity liquid oils (e.g. canola, soybean, corn). Examples of these oils include high-oleic sunflower, high-oleic canola, and high-oleic soybean oils.

From a health perspective, liquid oils are preferred for frying applications, while interesterified oils and fats, or blends of oils and interesterified fats, will often deliver most solid fat functionality with the lowest SFA level.

Naturally solid fats and their blends

Naturally solid fats and their solid fractions are all high in SFA. The more common naturally solid oils or fats that are relatively stable, functional, and require no partial hydrogenation include animal fats, palm oil, palm kernel oil, and coconut oil. There are other naturally solid vegetable oils found in local or regional areas that may function as non-PHO fat replacers, but these are the most commonly found and globally available.

ANIMAL FATS

A logical substitute for PHO fat is an animal fat. Fats, such as lard, tallow, and butter have been used as baking ingredients for centuries. They have not been completely replaced by PHO and are still used in food applications.

- **Lard** is used, in limited amounts, to make pie crusts.
- **Tallow** is a rendered form of beef or mutton fat primarily made up of triglycerides. Commercial tallow commonly contains fat derived from animals, such as pigs
- **Butter or anhydrous milk fat** continues to be perceived as a high- quality natural product compared to other animal fats. Butter is typically used in high-quality applications, such as puff pastries, croissants, and other laminated products. The characteristic desirable natural flavor, color, and odor of butter makes it an attractive choice for artisanal and high-quality food products.

In general, several barriers prevent the widespread use of tallow and lard - and to an extent butter - in baking as a full replacement for PHO fat:

- Religious limitations Many foods and food manufacturing facilities require religious certification which do not permit tallow and lard.
- Animal fats contain relatively high levels of saturated fat, which is a risk factor for heart disease Consequently, public health officials do not consider them to be a healthy replacement fat.
- Animal fats are not as versatile as PHO with respect to physical properties and functionality. They do not have consistent melting points or solids levels.
- The cost of butter can make this option prohibitive when the final price of the food is a primary concern.
- Ruminant fats (e.g., tallow and butter) also contain 4–6 % of natural *trans* fatty acids.

PALM OIL

Widespread commercial cultivation of palm oil began in the 1970s. Today, palm oil is the largest source of vegetable oil in the world. Palm oil has a soft semisolid texture at room temperature and is composed of a natural balance of 50% saturated fat and 50% unsaturated fat, making it suitable for some non-PHO fat replacements. Containing

just 10% polyunsaturated linoleic acid and no linolenic acid, it is inherently resistant to oxidation (rancidity) resulting in a naturally long shelf life.

Palm oil is compatible with bakery applications because it has a useful solid profile for functional applications and tends to form small beta-prime crystals. These small crystals impart a smooth texture to the fat and effectively entrap air during the creaming process. Air entrapment is needed to impart a desirable light texture and high volume to the food after baking. Palm oil can be used as an all-purpose shortening without further processing.

Despite its versatility, palm oil as a non-PHO replacement has drawbacks:

- Palm oil has a slower crystallization rate compared to PHO fats, requiring more time for crystallization to occur in the fat. This is known as "post-hardening."
- Palm oil has a narrower working temperature range than PHO fats, so palm oil may need to be blended with fractions or other oils to extend the working range (see below).
- For applications that do not require solid fat (e.g. frying), palm oil is not a healthy option because it contains about 50% saturated fat. High-oleic oils are much lower in saturated fat.
- Palm oil is often the most economical (but not the healthiest alternative) for applications needing solid fat. Interesterified and blended fats and oils can be designed to deliver the same solid fat functionality at lower SFA levels.
- Sustainability considerations and human rights issues must also be addressed. Some certification systems for sustainable palm oil are in place.

PALM KERNEL AND COCONUT OIL

Both palm kernel and coconut oil have unique solid profiles. Though they have high levels of solids at lower temperatures, the solids decrease sharply as temperatures increase. Their narrow solid temperature ranges and sharp melting behavior make them desirable in specific food applications but limit their use.

These oils are also very high in saturated fat and their availability and cost can be a drawback. They are, however, useful for blending and interesterifying with palm oil, liquid vegetable oils, or fractions to achieve certain melting behavior and solids profiles.

SHEA BUTTER

Shea butter is the fat extracted from the nut of the African shea nut; it has a melting point near body temperature. It is also high in saturated fat.

Shea butter and its fractions have solid fat profiles that are highly suited for use in blends with other non-PHO fats, such as a cocoa butter replacement for confectionery and bakery applications. The drawback to using shea butter in food applications is its limited availability and high cost, although its production is being expanded.

Fractions of naturally solid fats and their blends

Palm oil, palm kernel, and other fats that are naturally solid fats contain many structurally unique TAGs, each with different melting points and physical properties. Many of these components can be separated from the original liquid oil by a process called fractionation, which can be accomplished by either a physical process (dry) or with the use of a solvent. In the physical fractionation process, oil is first heated to melt all the solids, then it is cooled slowly under controlled conditions to maximize the formation of large crystals of the highest melting components. A high-pressure press is used to separate the suspended crystals by forcing the liquid oil though a filter.

SEPARATING PALM OIL COMPONENTS

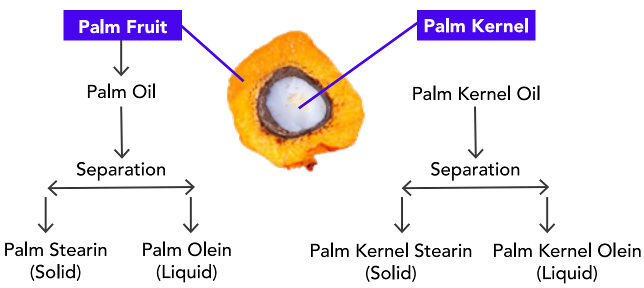


Figure 8 Fractionation of Palm and Palm Kernel oils. **Source:** Institute of Shortening and Oils (2016). *Food Fats and Oils*, Tenth Edition.

The solid fat crystals are retained on the filter and collected separately. In a solvent fraction process, heated oil is rapidly crystallized in the presence of a solvent, followed by filtration. This improves the separations of the solid fat crystals from the liquid oil.

In this way, the original oil is converted into two completely different fats, one with a lower melting point called *olein* and one with a higher melting point, called *stearin*. Olein and stearin fractions of palm oil and palm kernel oil still contain many different TAGs. Figure 8 is a pictorial overview of the products from a fractionation process for palm and palm kernel oils.

The palm olein fraction is mainly liquid at room temperature, with minimal solids. The oxidative stability of palm olein may be better than that of vegetable oils. Palm olein can replace PHO in frying applications. However, palm olein is high in saturated fat (about 40%) and vegetable oils — especially high- oleic oils (<10% SFA) — are preferred from a health perspective. Palm stearin is mainly solid at room temperature. It can be blended with palm oil or palm olein to increase the solids content to impart desired melting and increase solid fat contents. Blending a small amount of palm stearin with palm olein can produce a fat having a lower melting point and fewer solids than palm oil alone.

Each fraction can be further fractionated under new conditions to generate additional fractions. A third fraction (palm mid-fraction) can be produced by further fractionation of palm olein or stearin, and is often used in confectionery applications.

Interesterified fats and oils

Interesterified oils are a major source of non-PHO fats and oils. Interesterification is used to rearrange fatty acids within and between oil and fat molecules. Creating these new TAGs results in fats with customized melting and solid fat profiles. The interesterification of blends of fats and oils can produce an almost unlimited variety of fats with different physical properties to make healthier options with lower SFA. A chemical catalyst or an enzyme is used to redistribute the fatty acids in TAG.

Chemical interesterification can be carried out to equilibrium to achieve a fully random distribution of fatty acids in the TAG molecules. It can also be interrupted to provide partially rearranged fats. Enzymatic interesterification may achieve a more limited amount of rearrangement depending on the enzymes used.

The interesterification process can be used on any fat or combination of fats: blends of liquid oils, palm oil, palm kernel oil, blends of palm and palm kernel oils, fractions and blends of palm and palm kernel oils, or fully hydrogenated oils. An example of a functional, interesterified all-purpose baking shortening is an interesterified blend of a liquid high-oleic oil (such as high-oleic sunflower, high-oleic canola, or high-oleic soybean) with a fully hydrogenated oil to form a fat that performs similar to the PHO-based all-purpose shortening. For such a blend, the interesterification process takes away the "waxy" melt profile of a fully hydrogenated fat and also results in a lowered saturated fat content than that of the PHO-based shortening.

Interesterified fats or blends of palm, palm kernel, or their fractions can be used as the structuring fat (hardstock) in blends with liquid oils to provide faster crystallization rates and better solid fat profiles. These interesterified fat and liquid oil blends can be used to make margarines for retail or bakery applications. Blending interesterified hardstocks with liquid oil can also result in products with the lowest possible SFA levels. These margarines and spreads may contain as little as 25% SFA; contrast this with butter fat comprising 60% SFA and 4% TFA.

The interesterification process requires substantial investments. Not all fat suppliers have interesterification processes or unlimited capacity. Once the interesterification capacity is in place, it can actually be as economical or even less expensive than the partial hydrogenation process due to the high costs of hydrogenation catalysts. The need for larger investments may restrict the use of interesterification to large commercial applications.

Blends of naturally stable fats, fractions of fats and oils, and/or interesterified oils and fats

A variety of palm oil–based fats can be developed by blending palm oil with palm kernel oil, and/or fractions of palm oil or palm kernel oil. Blends of any of these with other liquid vegetable oils extend the range and functionality of these fat products.

For example, palm stearin can be blended with palm oil to raise the melting point and solid profile of the palm oil when the palm oil is too soft to handle or too slow to crystalize for an application.

Alternatively, small amounts of liquid oil, such as soybean or canola oil, can be blended in to allow a softer solid profile at lower temperatures for added pliability while maintaining the melting point and higher solid profile at the elevated temperatures required for certain food applications.

Care must be taken when blending in higher-melting fats to raise melting points and solid profile, because they can leave a coating in the mouth and create waxiness in the food product. Adding higher melting fats to raise the melting points and solid profile of a blended fat should be balanced to maintain the mouthfeel and texture of the product.

One drawback to creating finished commercial products from several components is that dedicated tanks are needed for each component. Tanks are often in short supply at fats and oils facilities. Furthermore, the manufacturer will need a blending system that can accurately deliver each type of oil in the proportion required in the finished blend.

On the other hand, using a single non-PHO fat in several applications may not impart the desired characteristics to all food products. The food manufacturer may require multiple tanks for all the non-PHO fats that may be needed to achieve these characteristics. Otherwise, a compromise in the finished food's characteristics will be required.

Considerations in finding a PHO replacement fat

There are many points to consider in the search for fats and oils that are free from industrially produced TFA. The replacement fat or oil must provide the functional characteristics of the PHO fat being replaced, such as flakiness, firmness of texture, crispness, or appearance in the finished product. If the familiar properties are not matched, it is possible consumers will reject the product.

A second consideration is maintaining the shelf life or flavor stability of the finished food product. When evaluating non-PHO replacement fats, alternatives with an oxidative stability similar to the PHO fat should be considered first. Alternatives with lower oxidative stability may require additional measures to protect the non-PHO fat and the finished food. Adding an antioxidant to the fat provides additional protection during handling and storage of the fat. The packaging material of the finished food can also be upgraded to minimize oxygen migration, or the distribution patterns of finished products can be changed to minimize storage times.

Trial and error are often a central part of evaluating a non-PHO replacement fat. Larger suppliers will have a range of non-PHO formulations for different applications and may need to evaluate non-PHO alternatives from several suppliers.

Other points to consider in the development of non-PHO fat alternatives include:

- The sustainability and environmental impact of the fats and oils being used and replaced.
- The health and nutritional guidelines designed to minimize the saturated fatty acids (SFA) in the food products. Ideally, the SFA level of the non-PHO replacement fat should be lower than the combined SFA and TFA level in the PHO fat it is replacing.
- The regulatory requirements of each market country, such as standards of identity of food products and approval of specific food additives (antioxidants, emulsifiers, stabilizers, dough softeners).
- The religious requirements of consumers.
- The capacity of food manufacturers to store the non-PHO replacement fats in their facility and their ability to make needed process changes with existing equipment. Introducing a non-PHO alternative may require modifications to the plant facility storage handling system and processing conditions.
- The fat supplier's ability to provide the non-PHO alternative consistently and cost effectively in sufficient quantities.
- The cost differences of the finished foods.
- The seasonal and regional variations that affect food manufactures, such as functional characteristics variations in temperature and humidity during the year. This variation may possibly require formulation modifications to accommodate seasonal changes (such as summer or winter formulas).

When formulating a non-PHO replacement fat, desired functionality and characteristics of the replacement fat should be managed. One of the key characteristics is to measure and understand the solid fat content (SFC) of both fats (PHO fat and non-PHO replacement fat) for a targeted application at temperatures of processing, eating, transportation, and storage.

In general, SFC is measured at temperatures ranging from 10 °C to 40 °C. A specific SFC profile is required for a targeted application. A first approximation for replacing PHO fats in is to produce trans-free fats with the same SFC as the original fat. However, matching the SFC alone usually does not result in a successful fat replacement. Overall crystallization properties of the replacement non-PHO fat, such as crystallization kinetics, polymorphism and melting properties, should be considered. Consumers can experience different textural properties in a food if a replacement is based solely on the SFC of a PHO-fat. Understanding the relations among crystallization behavior, microstructure, and mechanical properties of fats is necessary for a successful replacement.

Figure 9 shows SFC profiles of selected PHO fats and non-PHO replacement fats formulated using different technologies such as physical blends of fats and oils, interesterification of a fat, or interesterification of blends of fats and oils. In addition to fats and oils, different functional ingredients, such as emulsifiers, structuring agents, and antioxidants, are commonly used in formulating non-PHO replacement fats. In general, the choice of ingredients in formulation will depend on legislation, cost, desired functionality, supply chain, sustainability, health, and marketing demands.

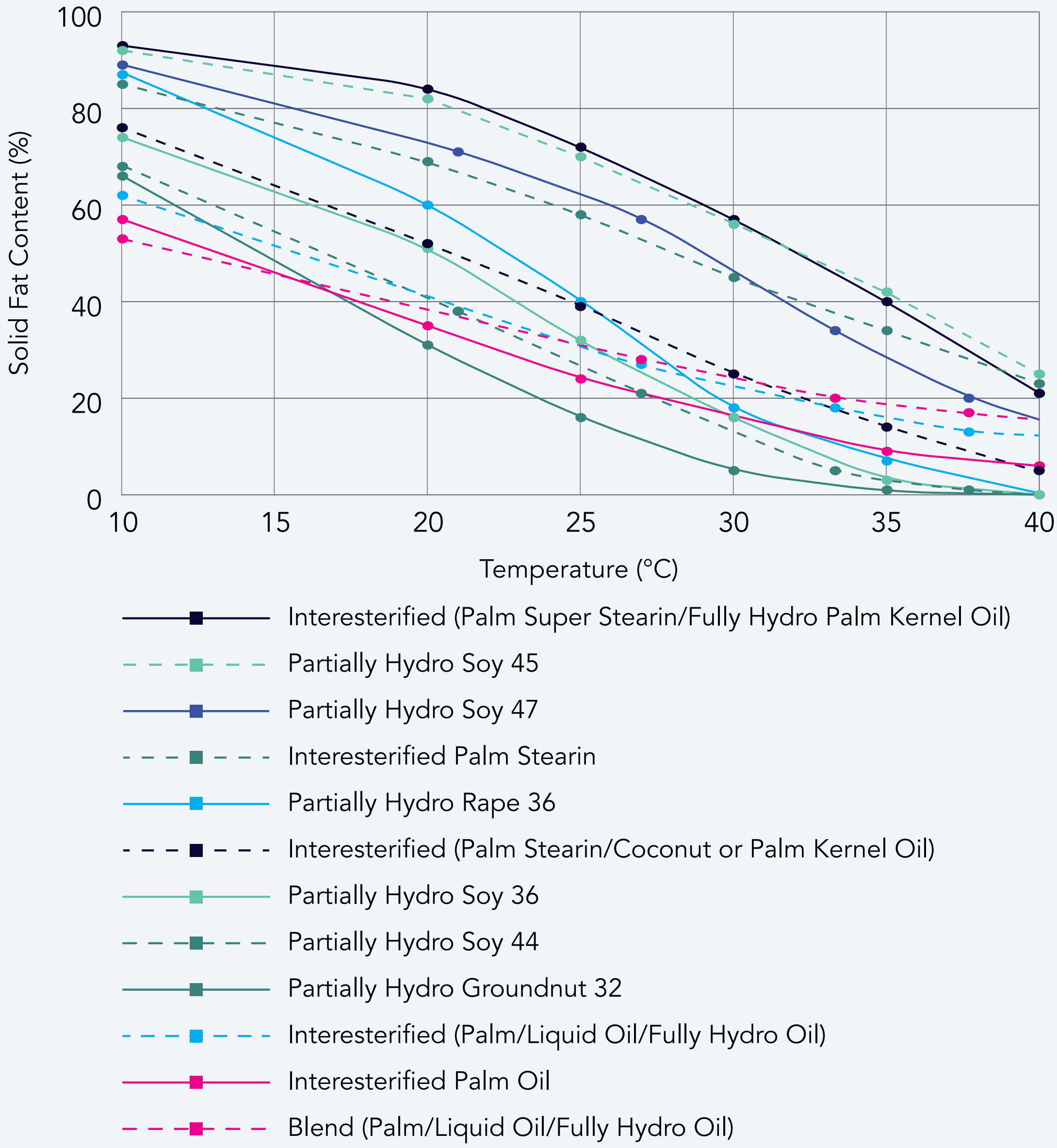


Figure 9 SFC profiles of PHO fats and low trans replacement fats formulated using different technologies such as physical blending and interesterification. Data provided by Cargill, Inc.

This figure illustrates how temperature affects the physical behavior of common PHO fats and non-PHO replacement fats. When exploring alternatives, understanding the melting curves of non-PHO fats is key to identifying ingredients that deliver comparable processing characteristics (during manufacturing) and consumer experience for the full range of features that relate to taste and quality (e.g., mouthfeel, viscosity, stability, firmness, spreadability, etc.). Physical blending and/or interesterification offer opportunities to deliver non-PHO fats that have functional properties similar to PHOs.

Formulating with non-PHO replacement fats requires knowledge of the desired functionalities and characteristics for the targeted product application to achieve successful product development. Figure 10 (Courtesy of Cargill, Inc.) is a table of several food categories (margarine, bakery, confectionery, frying, and dairy) with important functionalities or characteristics of product applications included. The figure also includes multiple non-PHO replacement fat options for specific product applications. For example, seven different non-PHO replacement fat options are available for bakery fillings to satisfy customers working in different bakery and confectionery environments.

TYPE OF APPLICATION	ALTERNATIVE	TYPE OF OILS	HEALTH CHARACTERISTICS	RELATIVE VALUE	COMMENT
BAKING MARGARINES (SOFT)	Interesterified oils with vegetable oil	Palm and PK stearins, with canola oils	High in MUFA Moderate in n-6 PUFA High in n-3 PUFA Low in saturates	Medium to high cost impact High health impact	
	Blending of soft oils and highly saturated oils	Palm oil or palm stearin and general vegetable oils	High in MUFA Moderate in n-6 and n-3 PUFA Moderate in saturates	Low to medium cost impact Medium health impact	n-6 and n-3 content depends on choice of vegetable oil
	Interesterified oils with vegetable oil	Palm and PK stearins, with soya oils	Moderate in MUFA High in n-6 PUFA Moderate in n-3 PUFA Moderate in saturates	Medium to high cost impact Medium health impact	
		Fully hydrogenated vegetable oils and liquid vegetable oils, with vegetable oils	Some MUFA High in n-6 PUFA Moderate in n-3 PUFA Moderate in saturates	Medium to high cost impact Medium health impact	n-6 and n-3 content depends on choice of vegetable oil
BAKING MARGARINES (HARD AND LAMINATING)	Blending of soft oils and highly saturated oils	Palm oil or palm stearin and high-stability vegetable oils	Moderate in MUFA Small amount of n-6 and n-3 PUFA High in saturates	Low to medium cost impact Low health impact	Dietary advice is to limit consumption of baked products high in saturates
	Interesterified oils with vegetable oil	Palm and PK stearins, with soya oils	Moderate MUFA and n-6 PUFA Small amount of n-3 PUFA High in saturates	Medium to high cost impact Low to medium health impact	Dietary advice is to limit consumption of baked products high in saturates
		Fully hydrogenated vegetable oils and liquid vegetable oils, with vegetable oils	Some MUFA Moderate in n-6 and n-3 PUFA High in saturates	Medium to high cost impact Low to medium health impact	Dietary advice is to limit consumption of baked products high in saturates

TYPE OF APPLICATION	ALTERNATIVE	TYPE OF OILS	HEALTH CHARACTERISTICS	RELATIVE VALUE	COMMENT
BAKERY OR FOOD PROCESSOR SHORTENING (SPRAY/ LIQUID)	General vegetable oils	Canola or soya oils	High in MUFA or n-6 PUFA High in n-3 PUFA Low in saturates	Low cost impact High health impact	Poor oxidative stability Addition of antioxidants can improve oxidative stability
	Medium- and high-stability vegetable oils	High oleic canola oil High oleic sunflower oil	High in MUFA Small amount of n-6 and n-3 PUFA Low in saturates	Low to medium cost impact Medium to high health impact	Better oxidative stability than general vegetable oils Highest amounts of n-6 and n-3 are preferred from a health perspective
		Low linolenic soya oil Mid oleic sunflower oil	High in MUFA or n-6 PUFA Low in saturates	Low to medium cost impact Medium to high health impact	Better oxidative stability than PUFA-rich vegetable oils Highest amounts of n-6 and n-3 are preferred from a health perspective

TYPE OF APPLICATION	ALTERNATIVE	TYPE OF OILS	HEALTH CHARACTERISTICS	RELATIVE VALUE	COMMENT
BAKERY OR FOOD PROCESSOR SHORTENING (SOLID)	Blending oils for solids and performance	Palm oil or palm stearins or fully hydrogenated oil, and medium-stability vegetable oils	High in MUFA Moderate in n-6 PUFA High in n-3 PUFA Low in saturates	Low to medium cost impact High health impact	Emulsifiers may be added for increased functionality
	Interesterified oils with vegetable oil	Palm and PK stearins, with canola oil	High in MUFA Moderate in n-6 PUFA High in n-3 PUFA Low in saturates	Medium to high cost impact High health impact	
		Palm and PK stearins, with high oleic canola oil	High in MUFA Small amount of n-6 and n-3 PUFA Low in saturates	Medium to high cost impact Medium to high health impact	Higher amounts of n-6 and n-3 are preferred from a health perspective but may give insufficient oxidative stability and shelf life
	Blending oils for solids and performance	Palm oil or palm stearins or fully hydrogenated oil, and medium-stability vegetable oils	Moderate in MUFA Moderate in n-6 and n-3 PUFA Moderate to high in saturates	Medium cost impact Low to medium health impact	Lower saturated is preferred but may not give the required functionality
	Interesterified oils with vegetable oil	Palm and PK stearins, with high oleic canola oil	High in MUFA Small amount of n-6 and n-3 PUFA Moderate to high in saturates	Medium to high cost impact Low to medium health impact	Lower saturated is preferred but may not give the required functionality
		Fully hydrogenated vegetable oils and liquid vegetable oils, with liquid vegetable oils	High in MUFA Small amount of n-6 and n-3 PUFA Moderate to high in saturates	Medium to high cost impact Low to medium health impact	Lower saturated is preferred but may not give the required functionality

Figure 10 Healthier alternatives for replacement of trans fats by food applications from WHO Replace Package Module 2

Approaches for non-PHO Fat Replacement in Baking and Confectionery Applications

Most bakery and confectionery applications rely heavily upon the functionality of the solid fat. The melting curves, texture, crystal structure, and morphology are very important in food products. For example, it is crucial that baked goods have a certain solid fat content (SFC). In these products, solid fats provide pliability to dough and also give layer, spread, or discrete distribution of fat depending upon the product requirement. Some of the functions that fat plays include structuring, allowing lamination, providing lubricity, and tenderizing. These functions translate into desired texture, flakiness, structure, and tenderness of the finished product and can increase the shelf life by delaying staling. As a result, many bakery and confectionery products are high in saturated fats.

Baking applications using fats and oils as a primary ingredient can be broken down into those using hard wheat, those using soft wheat, and those using sugar as a principal ingredient.

Bakery products using hard wheat: breads, rolls, laminated doughs (Danish, Puff Pastry and Croissants), and yeast-raised doughnuts

BREADS AND ROLLS

Fats and oils in bread and rolls improve the volume developed during baking and provide lubricity to aid in the slicing of the product. Traditionally, solid fats (referred to as all-purpose shortenings) have been used in breads and rolls. Over the last decade or so, liquid oils such as soybean, canola, and sunflower containing an emulsifier (like alpha-monoglycerides) have been used successfully to replace all-purpose shortenings.

- Potential non-PHO alternatives would be: liquid oils with added monoglycerides; blends of palm oil and liquid oils (soybean, canola); and lard, palm oil, blends of palm oil, and palm stearin.
- Functional considerations: Using a liquid vegetable oil instead of a solid fat in the dough in this application is possible but may result in weak dough strength, which can result in the collapsing of the top crust. This can be overcome by adding a dough strengthener additive to the dough if regulations permit.

LAMINATED DOUGHS

Laminated doughs are the basis for numerous specialty bakery products found around the globe. Laminated pastries are manufactured by first making a thin layer of dough and spreading a thin layer of fat over the dough. The double layer is folded back and forth over itself many times until it forms a block of dough with up to 100 folds of fat layered with dough. When the dough is baked, the thin dough layers separate and start to harden and rise. The result is many thin, hard, crispy flakes with large spaces in between.

The shortening needs to be very pliable (or "plastic") to withstand the layering process. The shortening needs to flow with the dough as it is sheeted and not break through the dough or be absorbed into it (which can result in poor rise or distorted shapes in the final product). In addition, it must be "temperature tolerant" and not become too hard or too soft as the temperature of the product or the bakery shop rises or falls during the dough preparation process. Different applications require different solid profiles, so each non- PHO alternative must be designed to match the requirements of the laminated products, including Danish, puff pastry, and croissants.

The solid profile requirements of each product can be met using the various blends of structuring fats (hardstocks) and liquid oil mentioned in earlier sections.

DANISH AND CROISSANTS

Danish and croissants are yeast-raised doughs that obtain their volume from the lamination and rise of the dough when baked. A roll-in shortening or margarine for this laminated dough requires a broad temperature range in which the fat or margarine is pliable or plastic.

- Potential non-PHO alternatives: interesterified fats (hardstocks) blended with liquid oils (often the lowest SFA alternative); blends of palm oil and/or palm stearin and/or palm kernel oils with liquid oil or butter.
- Functional considerations:
  - If the fat is too hard when rolling out the dough and applying fat to create layers, it may tear. If it is too soft, the fat may soak into the dough, keeping it from layering.
  - Danish doughs are developed by holding at elevated temperatures to proof the dough. If the melting point of the fat is too low (at or below proofing temperature) the fat in the dough will melt losing the layering effect when the Danish is baked.

PUFF PASTRY

Puff pastry is a more developed laminated dough that gets most of its rise from the moisture coming from the butter or margarine typically used in making this pastry. To achieve the voids, the butter or margarine may be folded into continuous layers but are often added in small pieces while sheeting out the dough. The puff pastry margarines typically have a higher melting point and solids profile than Danish roll-in shortening or margarine.

- Potential non-PHO alternatives: interesterified fats (hardstocks) blended with liquid oils (often the lowest SFA alternative); butter and/or blends of palm oil; and palm stearin.
- Functional considerations: a baker's margarine with a melting point or solids profile that are too high may cause the dough to tear when rolling it out. A melting point and solids profile that are too low may cause the layering of the dough at baking to be lost.

YEAST-RAISED DOUGHNUTS

Doughnuts and similar fried yeast-raised sweet dough products have fat from two sources: a dough component (typically an all-purpose shortening) and fat absorbed during frying.

- Potential Non-PHO alternatives:
  - dough fats — interesterified liquid oil and fully hydrogenated oil, blended with liquid oil (often lowest SFA alternative), palm oil, and blends of palm oil and palm stearin.
  - frying fats — interesterified liquid oil and fully hydrogenated oil, blended with liquid oil (often lowest SFA alternative), palm oil, and blends of palm oil and palm stearin.
- Functional considerations: the melting point of the frying fat is important if the doughnut will be glazed or sugar-coated. If the melting point of the frying fat is too low, the liquid fraction of the fat will migrate to the doughnut surface and dissolve the glaze or sugar coating. If the product is consumed soon after frying, this problem is minimized. Also, the frying oil must be sufficiently stable from oxidation to maintain an acceptable doughnut flavor.

Bakery products using soft wheat: cake, cookies, crackers, pie crust, flaky biscuits

CAKE

Cakes, cake doughnuts, muffins, and other baked leavened goods rely strongly on the solid profile of the fat, which provides tenderness and structure by entrapping air bubbles in the batter. The shortening, which is typically an all-purpose shortening, may contain an emulsifier to aid in air entrapment. If an emulsifier is used, care should be taken that this ingredient is also made from a non-PHO alternative rather than a PHO that can contribute TFA to the shortening.

Certain cake items, such as cake doughnuts, are fried rather than baked.

- Potential non-PHO alternatives: palm oil, blends of palm oil and palm stearin, interesterified fats (lowest SFA alternative), palm oil, blends of palm oil and palm stearin, and/or coconut or palm kernel oil.
- Functional considerations: all-purpose shortening could contain one or more emulsifiers.

COOKIE

The fat used in cookies is typically an all-purpose shortening that helps provide lubricity during manufacturing, and air entrapment and tenderness in the finished baked product.

- Potential non-PHO alternatives: interesterified liquid oil and fully hydrogenated oil, blended with liquid oil (lowest SFA alternative), blends of palm stearin and liquid oil (soybean, canola), palm oil, and blends of palm oil and palm stearin.
- Functional considerations:
  - The type of fat and its level in the cookie formula can affect the cookie spread during baking. When replacing a PHO with a non-PHO fat, the fat level may need to be raised or lowered to obtain a desired spread in the baked cookie.
  - The all-purpose shortening may contain a small amount of a liquid oil (soybean or canola) to soften the solids profile and lower the level of saturated fatty acids in the blend for a better nutritional profile.

CRACKERS

Fat is used two ways in cracker production. It is used to provide lubricity during dough preparation and sprayed onto the cracker surface right after baking to provide lubricity when eaten.

- Potential non-PHO alternatives: for dough — blends of palm oil, palm stearin, and liquid oil (soybean, canola (lowest SFA alternative), and palm oil, or blends of palm oil and palm stearin); for spray oil — liquid oils with antioxidants added (lowest SFA), palm, palm olein, and coconut oil.

- Functional considerations:
  - The oxidative stability of the spray oil is important, as it is added while the cracker is hot and over a wide surface area, which can contribute to oil oxidation and the development of off-flavors. If liquid oils with low oxidative stability are used, an antioxidant may be required.
  - Coconut oil can be used for the spray oil, but its high in saturated fatty acid content and may be cost prohibitive.

PIE CRUST AND FLAKY BISCUIT

The fat used in making pie crust and flaky biscuits is important, as it contributes to the flakiness and tenderness of the final product. Lard is traditionally used to provide flakiness, but butter, margarines, or all-purpose shortening can also be used.

- Potential non-PHO alternatives: liquid oil interesterified with fully hydrogenated oil (lowest SFA) margarines, lard, butter, palm oil, and blends of palm oil and palm stearin.
- Functional considerations:
  - The fat temperature may be important in imparting the desired flakiness to the pie crust or biscuit. Cooling the fat before cutting it into flour aids in making a flaky final product. A fat that is too soft for the ambient temperature will become oily and the finished product will be too tender and fall apart.
  - Inconsistent texture (too hard or too soft) in the shortening can cause issues with the dough hydration and sheeting leading to dough tears or oiling out (bleed through) resulting in the dough falling apart.

Bakery products using sugar as a primary ingredient are filler fats and icings

FILLER FATS

Fillings used in sandwich cookies and sugar wafers are a mix of fat and sugar or dextrose. They require a fat that has a sufficiently high solids profile at ambient temperature to allow the filling to be applied to the cookie or wafer and hold the two ends together without sliding. The fat must melt at body temperature to prevent a waxy mouthfeel. The need to maintain structure and hardness in filler creams implies that lower SFA alternatives are generally very difficult to use.

- Potential non-PHO alternatives: palm oil, interesterified palm and/or coconut or palm kernel oil, blends of palm oil and palm stearin, palm and coconut or palm kernel oil; or palm oil and palm kernel stearin.
- Functional considerations: The ambient temperature in the bakery shop is going to be important in determining the choice of fat blend. Higher ambient temperature will require a higher level of solids, but care is needed to keep the melting point as close to body temperature as possible.

ICINGS

Cake and baked good icings are typically highly aerated and made by creaming powdered sugar and fat together to make a light textured to be spread on cakes and other baked goods. Typically, butter or an all-purpose type shortening that is highly emulsified are used in this application.

- Potential non-PHO alternatives: interesterified fats blended with liquid oils (lowest SFA) blends of palm oil and palm stearin oils with liquid oils, butter, highly emulsified fats based on palm oil, blends of palm and palm kernel oils.

- Functional considerations:
  - The all-purpose shortening could contain one or more emulsifiers to improve the aeration of the icing.
  - The attributes of an icing include its body (stiffness) and lightness, which are both affected by the solids profile of the fat. The icing should remain stable at ambient or slightly elevated temperatures. It should not separate or oil-out on standing and should not leave a waxy mouthfeel.

CONFECTIONERY COATINGS AND FILLERS

As described earlier, PHO fat can be found in certain confectionery products as a replacement for cocoa butter used in chocolate flavored coatings. The PHO based confectionery coatings can be easily replaced with non-PHO alternatives and their blends to provide highly functional chocolate flavored coatings and center creams in baked and sweet confectionery foods. However, given the functional requirements for cacao butter replacements, lower SFA alternatives are generally very difficult to use.

COATING/ENROBING FATS AND CENTER CREAMS

Many food products are coated or enrobed with a layer of chocolate. The traditional cocoa butter in the chocolate is often replaced with lower cost functional alternatives which are classified as cocoa butter substitutes (CBS) and cocoa butter replacers (CBR). In this application, both the CBS and the CBR provides coating structure and gloss and carries the chocolate or confectionery flavor. The CBS requires tempering, just as with cocoa butter-based coatings and they are not very compatible with cocoa butter.

The role of a center cream is much different than the role of coatings, providing flavor release and lubricity. The confectionery fats in this application must be compatible with the coating fat if they are in contact to avoid oil migration, resulting in loss of desired texture or appearance.

- Potential Non-PHO alternatives: CBS and CBR, palm kernel oil, fully hydrogenated palm kernel oil, fully hydrogenated palm kernel olein, palm kernel fractions, shea butter, shea butter fractions, blends of these oils mentioned, and more recently interesterified blends of palm, palm kernel, and/or their fractions.
- Functional considerations:
  - The solid fat profile should be complex, with higher solids at the lower temperature to maintain the structure of the coating during application and handling of the food while maintaining lower solids at body temperature.
  - The fat should not produce a waxy mouth coating when the food is consumed.
  - The non-PHO alternative should have the tempering process, set times, and melting characteristics that match the production capabilities and finished product needs for mouthfeel and heat stability.
  - Confectionery products can be more demanding and complex than other application areas. Finding a suitable replacement for a PHO fat in this application may be difficult at first. However, there are many commercially available, highly specialized fats that will satisfy this application's functional demands.

FUNCTIONALITY / NON-PHO REPLACEMENT FAT OPTIONS	MARGARINE	BAKERY				CONFECTIONERY			FRYING		DAIRY	
	Cooking/ Spreading	Laminated Dough	Cookie/Biscuit/ Pie Crust	Cakes	Bakery Fillings	Confectionery	Coating/ Enrobing	Confectionery fillings	Frying	Doughnut Frying	Milk Fat Replacer	Ice Cream
Functionality												
Texture: loss of solid fat content @ room temperature	x				x	x	x	x		x	x	
Plasticity: wide plastic range	x	x										
Crystallization behaviour / speed	x	x	x	x	x	x	x	x		x	x	
Line speed during processing / Processability	x	x	x	x	x	x	x	x				
Post crystallization	x	x	x		x	x	x	x			x	
Final product volume (air incorporation)				x	x			x				x
Flavor	x	x	x						x	x		
Flavor release (melting profile)	x	x	x	x	x	x	x	x			x	x
Quick melting: narrow plastic range	x	x			x	x	x	x				
Oil/fat migration	x		x		x	x	x	x		x	x	
Fat blooming					x	x	x	x		x		
Oil retention	x				x	x		x	x	x		
Oxidation (bulk storage and finished product)	x	x	x	x	x	x		x	x	x	x	
Final product shelf life	x	x			x	x	x	x		x	x	
Heat stability	x	x			x	x		x	x	x		x
Appearance					x	x	x		x	x		
Non-PHO Replacement Fat Options												
Palm oil and/or fractions	✓		✓	✓	✓	✓		✓	✓	✓	✓	✓
Coconut or Palm kernel oil	✓					✓		✓			✓	✓
Blends of tropical oils												✓
Blends of soft seed oils			✓	✓					✓			
Blends of non-hydrogenated + fully hydrogenated oils				✓								✓
Interesterified blends - non-hydrogenated	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	
Interesterified blends - non + fully hydrogenated	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	
Interesterified blends - non + fully hydrogenated + seed oils	✓	✓	✓	✓	✓	✓	✓	✓		✓		
Fats and oils with emulsifiers (e.g. (mono &) diglycerides)	✓		✓	✓	✓	✓		✓				✓
Fats and oils with structuring agents (e.g. starches)	✓		✓	✓	✓	✓		✓				
Fats and oils with antioxidants	✓			✓		✓			✓		✓	
High stability oils (high oleic oils)					✓				✓			

Figure 11 Product and Functionality Matrix and Related Non-PHO Replacement Fat Options in Margarine, Bakery, Confectionery, Frying, Ice Cream and Dairy Categories
Data provided by Cargill, Inc.

Explanation of functionalities

TEXTURE: Loss of solid fat content @ room temperature

Solid fat is needed to provide structure to the fat which in turn will give texture to the food product. As an example, think of margarine (with more solid fat) compared to Canola or sunflower oil (very low in solid fat). Solid fat content strongly influences mechanical properties of fats.

PLASTICITY: wide plastic range

Plasticity refers to a fat having a relatively high content of solid fats over a broad temperature range, making it foldable and keeping its structure at different temperatures. This is especially important for margarines and dough fats for croissant and Danish pastry type of products.

CRYSTALLIZATION BEHAVIOUR / SPEED

Crystallization is the process of solid fat formation, which happens when the fat (in the food product) goes from a higher to a lower temperature. The speed at which this happens determines the time this takes, which needs to fit with the food production process. In case crystallization continues after the production process, this can may negatively impact the food quality. In some cases, products are held at certain temperature/time (tempering) to reach the desired consistency and crystallization.

LINE SPEED DURING PROCESSING / PROCESSABILITY

If fat crystallization is part of the food production process, the time this takes needs to fit with the food production process. If not, processability is negatively impacted.

POST CRYSTALLIZATION

Depending on the fat type and the food production process, the fat can crystallize in an unstable form. Over time the crystal type can change, potentially leading to small hard fat lumps making it unpleasant to eat the food product (sandy, grainy).

FINAL PRODUCT VOLUME (AIR INCORPORATION)

In certain food products air incorporation is needed, for instance to make a cake fluffy and to make a biscuit filling lighter and creamier. Depending on their composition (fatty acid profile), some fats do a better job on this than others.

FLAVOR

Refined oils and fats are all quite neutral in taste when fresh but do have an own distinctive taste. The type of food processing as well as the time the product is kept, can change the oil taste to rancid.

FLAVOR RELEASE (MELTING PROFILE)

Especially in margarine and in fillings, the speed at which the fat melts impacts how fast or slow flavors are released.

QUICK MELTING: NARROW PLASTIC RANGE

Quick melting gives a cooling sensation in the mouth when a high content of solid fat quickly drops to a low level over a specific narrow temperature range. Think of chocolate and ice cream.

OIL/FAT MIGRATION

Migration happens when liquid oil or smaller fat molecules move through the product, for example resulting in biscuits/cookies being fatty in the outside.

FAT BLOOMING

Fat blooming is the result of part of the fat migrating followed by crystallization on the outside of the product, giving chocolate and confectionery products or biscuit a whitish look.

OIL RETENTION

Oil retention has to do with keeping liquid oil locked in the fat structure and thus in the food product. The type of fat determines the oil binding capacity. If the oil is not sufficiently retained, liquid oil will easily come out of the product as can be seen with (spreadable) margarines and peanut butter.

OXIDATION (BULK STORAGE AND FINISHED PRODUCT)

Oxidation produces rancid off-flavors in fats and oils. Different oils and fats are more or less sensitive to oxidation, depending on their composition (fatty acid profile). In general liquid oils are oxidized more easily than fats. Because of this, specific high-oleic oils have been developed which are much more resistant to oxidation than other oils due to their specific fatty acid composition.

FINAL PRODUCT SHELF LIFE

Shelf life of the final product will depend on the product type and can vary between days and years.

HEAT STABILITY

Different oils and fats are more or less sensitive to heat, depending on their composition (fatty acid profile). In general liquid oils are less heat stable than fats. Because of this, specific high oleic oils have been developed, which are much more stable due to their specific fatty acid composition. Heat stability is important for food products which are processed at high temperatures like frying or spray drying. Heat stability is a very important functionality in confectionery products especially at warm climates for product integrity and shelf life.

APPEARANCE

Whether or not a fat crystallizes will impact the way the food product looks. For fried products for instance, solid fat on the product surface will make it appear less shiny and less greasy.

Steps for successful implementation a non-HPVO solution are:

1

Know what you are looking for by identifying

- The key functionality of the fat required for the specific product application
- Any labelling requirements and/or compositional restrictions
- Potential cost limitations

2

Find the right alternative ingredient

- Work with your fat supplier, benefitting from their expertise
- Try different products on the market

3

Test the ingredient and product

- If a new fat is required, this might require product development as well as lab and potentially pilot-scale testing.
- Testing the (new) fat in the product on a small scale can potentially be done by the supplier and/or the food producer.
- It is recommended the food producer also does a production-scale trial.
- Sensory testing and shelf-life testing are often also included.

4

Launch the product

- after good outcomes of all previous steps

Measuring Trans Fatty Acids

Since the 1920s, analytical methods developed by the American Oil Chemists' Society (AOCS) have been internationally recognized and several are listed by the Codex Alimentarius Commission. Offered in several different formats, the Official Methods and Recommended Practices of the AOCS is essential for a lab testing edible fats and oils and similar compounds. AOCS has developed several methods for measuring trans fatty acids, including:

- Cd 14f-14 Rapid Determination of Total SFA, MUFA, PUFA, and trans Fatty Acid Content of Edible Fats and Oils by Pre-Calibrated FT-NIR
- Cd 14-95 Isolated trans Isomers, Infrared Spectrometric Method
- Ce 1g-96 trans Fatty Acids by Silver-Ion Exchange HPLC
- Ce 1h-05 Determination of cis-, trans-, Saturated, Monounsaturated and Polyunsaturated
- Ce 1j-07 cis-, trans-, Saturated, Monounsaturated, and Polyunsaturated Fatty Acids
- Ch 2a-94 trans Unsaturated Fatty Acids by Capillary Column Gas Chromatography

Finding help with sourcing and using non-PHO containing Fats and Oils (free from TFA)

The current supplier of the fat or oil you already use is the first place to inquire whether that fat or oil contains partially hydrogenated oils/TFA. If so, inquire about non-PHO alternatives available from that supplier. If that supplier cannot supply a non-PHO alternative, there are other fat and oil suppliers that can.

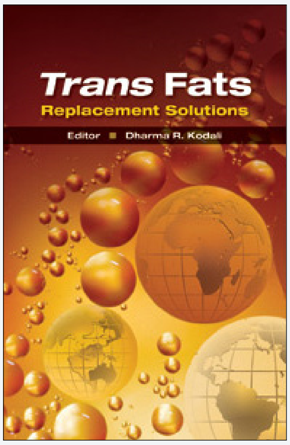
For technical support in replacing PHO fat and oil in recipes or formulas, the fat and oil supplier may be able to help.

There are corporate members of the American Oil Chemists' Society that have a global presence in supplying a variety of fats and oils solutions that do not contain TFA. They can also provide technical assistance in using their fats and oils in food applications. Those members and their websites are listed below. In addition, many subject matter experts are part of the AOCS online community called inform|connect and are available to answer technical questions.

This free resource is supported by AOCS and the AOCS Foundation and can be accessed at www.informconnect.org.

AOCS CORPORATE MEMBERS	WEBSITE
AarhusKarlshamn	www.aak.com
Archer Daniels Midland Company	www.adm.com
Bunge Loders Croklaan	www.bunge.com
Cargill, Inc.	www.cargill.com
Fuji Oil	www.fujioil.co.jp
Wilmar International	www.wilmar-international.com

Other Available Resources



Trans Fats Replacement Solutions

Edited by Dharma R. Kodali

This book provides a comprehensive understanding of the *trans* fats chemistry, labeling regulations, and *trans* fat replacement technologies. It also deals with worldwide trends and scenarios in terms of regulations and *trans* fat replacement solutions.

Replace Trans Fat: An Action Package to Eliminate Industrially Produced Trans-Fatty Acids, Module 2: Promote

A how-to guide for determining the best replacement oils and interventions to promote their use from the World Health Organization.