
1 Introduction

Frank T. Orthoefer¹ and Gary R. List²

¹FTO Foods, Knoxville, TN, USA

²USDA ARS NCAUR (Retired), Peoria, IL, USA

The fats and oils industry has changed and continues to renew itself. Historically, two major technological events have had a significant impact. These are (1) the development of new oils with modified fatty acid composition and/or distribution: the *trait-modified oils* (TMO) and (2) the substitution of animal fats for vegetable oils.

Trait-modified oils owe their existence to the development of new fats and oils through plant breeding biotechnology with the need for more suitable crop varieties to meet the demands of the marketplace. Two new oil examples are high oleic acid sunflower oil, developed through breeding and selection, and low linolenic acid soybean oil developed through mutation. Using analytical methods, mainly gas chromatography, has enabled the application of molecular biology to the modification of fatty acid composition. The rapid changes in molecular genetics and plant breeding have made what was once considered “novel” now routine practice. No longer necessary was conventional hydrogenation, a process that made all oils “equal” for food applications, all the way from frying to hard butter applications. Soybean oil could be stabilized by hydrogenation and its physical properties modified such

that it met the needs of most bakery or imitation dairy users. The formation of trans acids in this process was part of the expanded applications of hydrogenated oils which are no longer desired. Traits of oils based on fatty acid composition permitted the use of by-product oils: soybean, corn, and cottonseed oils.

The oil biotechnologist was motivated by loftier goals. Most of the impetus for these food scientists was not functionality but rather the negative health effects of trans fatty acid (Mensink and Katan 1990) and the mandate for labeling trans acids in the diet (reviewed by Hunter 2005). The Food and Drug Administration (FDA) mandates of 2003 regarding labeling of trans fats from partially hydrogenated oils in foods was the major push. Food technologists were challenged in the fields of reformulation, processing, and handling. All these methods were used to make the substitution seamless. Suddenly, oil producers and consumers were looking to the alternatives already available. Today's trait-modified oils include those from selective breeding, mutation, and genetic modification. Food formulators now, have a class of food oils that are not only more healthy but have a longer shelf-life. These "new" oils meet processor and consumer demands and are the functional alternative ingredients for foods.

1.1 SOURCES

There is a long list of plant and animal derived edible oils (Box 1.1). Four crops account for 84% of the total North American consumption of edible oils. Box 1.2 shows these oils, in their order. Soybean, corn, canola, and cottonseed oils are the top four. Prior to 1997, about 10% of the world's edible supply was consumed by industrial uses. Edible oil used industrially has now increased to 20.6%.

The characteristics of the trait-modified oils suitable for frying are:

1. Low linolenic – moderate stability, high deep fat flavor intensity.
2. High oleic – high stability, low deep fat fried flavor intensity, waxy/plastic flavor.
3. Mid Oleic- high stability, high deep fried flavor intensity.

Sharp differences exist between saturated fatty acid content, saturated short chain fatty acids, saturated long chain fatty acids, monounsaturated, and polyunsaturated fatty acids. The diversity in fatty acid composition

Box 1.1 Typical Fatty Acid Composition of the Principal Vegetable and Animal Fats and Oils in the U.S.

(% of total fatty acids)																															
	Butyric	Caproic	Caprylic	Capric	Lauric	Myristic	Pentadecanoic	Arachidic	Behenic	Lignoceric	Myristoleic	Palmitoleic	Oleic	MONO-UNSATURATED								POLY-UNSATURATED									
														SATURATED								UNSATURATED								18:2	18:3
														4:0	6:0	8:0	10:0	12:0	14:0	15:0	16:0	17:0	18:0	20:0	22:0	24:0	14:1	16:1	18:1		
Oil or Fat																															
Beef tallow						3	1	24	2	19		4	43	1												3	1				
Butterfat	4	2	1	3	3	11	2	27	1	12		2	29													2	1				
Canola								4		2			62													22	10				
Cocoa butter								26		34			34													3					
Coconut	1	8	6	47	18			9		3			6													2					
Corn								11		2			28													58	1				
Cottonseed						1		22		3		1	19													54	1				
High oleic canola								4		2			75													17	2				
High oleic safflower								7		2			78													13					
High oleic sunflower								4		3			79													11					
Lard					2			26		14		3	44				1									10					
Mid oleic sunflower								4		5			65													26					
Olive								13		3		1	71													10	1				
Palm kernel								8		3			15													2					
Palm						1		45		4			40													10					
Peanut			3	4	48			11		2			48				2									32					
Safflower								7		2			13													78					
Soybean								11		4			24													54	7				
Sunflower								7		5			19													68	1				

From: Food Fats and Oils. Institute of Shortening and Edible Oils. 1750 New York Ave., NW Suite 120, Washington DC. 20006. Ninth Edition Pg 26

Box 1.2 North American Edible Oil Consumption by Partial Hydrogenation Level

Type of Edible Oil	Amount* 10 ⁶ lb	% of Total	% Partially Hydrogenated [†]	Amount of Partially Hydrogenated Oils, 10 ⁶ lb
Soybean	17820	70.3	41.7	7431
Canola	2609	10.3	26.7	697
Corn	1722	6.8	36.1	622
Coconut	895	3.5	0	0
Cottonseed	695	2.7	17.7	123
Palm Kernel	529	2.1	0.4	2
Palm	434	1.7	0	0
Sunflower	423	1.7	23.5	99
Peanut	233	0.9	11.6	27
TOTAL	25360	100	35.5	9001

*Based on data from the Oil World Annual Report 2006.

[†]Based on a proprietary report conducted for Dow AgroSciences.

imparts differences in functional properties important for some food manufacture, for example frying, bakery shortenings, and salad oils.

Even processing technology is affected. Melt point, melting characteristics, and oxidative stability are associated with the degree of saturation and component fatty acids. Minor compounds also have an effect (O'Brien 2004).

Food processors have learned how to manufacture basestocks and blends for foods to optimize flavor, mouth feel, texture, and functionality. This led to interchangeability of whole oils with similar physical properties or processed products that may be based on them. Accessing suitable fats and oils has been left to price and availability. The trait-modified oils with modified fatty acid profiles may be positioned to enter the market as commodity oils with premiums either for contract supply or actual cost of identity preserved production, storage or processing.

1.2 PROCESSING

Through processing methods and blending, oil processors have extended the functional properties and utility of edible oils (O'Brien 2004; Weiss 1983). Hydrogenation further extended the range of modification and

utility of edible oils in shortenings, margarines, and frying fats. Hydrogenated basestocks and functional additives were used to create foods with appealing flavors, mouthfeel, lubricity, and texture. Meeting these standards through hydrogenation led to the ability to interchange various vegetable oils for formulation of processed products.

The most sustainable oil crops are palm, soybean, and canola oils. Other oils will continue to be produced but may require an advantage for market success. The trait-modified oils may provide another distinction for crops. The value or need for other oils will be to find means to use viable competitive edge through nutrition, production, processing or functionality. The genetic modification of oil traits is a new level of distinction for crops.

1.3 CONSUMER PREFERENCE AND LEGISLATION

Consumers are now more selective and have been conditioned to the dietary health benefits of fats and oils. The health benefits of polyunsaturated fats led to a restriction of dietary saturates, generally meat fats, and the emphasis on use of liquid vegetable fats (Kearney 2007). The extent of the health claims led to the Nutrition Labeling and Education Act of 1990 that limited claims such as “low in saturated fats” to food containing less than 1 g of saturated fat per serving. This restricted the use of the claim to vegetable oils with 7% or less saturated fats.

The health claim was extended to include process rearrangement of the TAG molecular structure. The implication was that process induced trans fatty acids formed in partially hydrogenated oils with a deviation of serum levels of low density lipoprotein (LDL), the “bad” cholesterol. The Institute of Medicine, National Academy of Science published a report suggesting that trans fat consumption should be kept as low as possible. The Center for Science in the Public Interest (1994) filed a petition with the FDA requesting the agency take steps to require trans fats to be listed on nutrition labels. The FDA later proposed a rule based on a number of credible scientific reports and expert panels: Trans Fatty Acids in Nutrition Labeling. Nutrient Content Claims and Health Claims 2003. The Final Rule became effective in January 2006.

Today the link between trans fat and coronary heart disease is no longer disputed by consumers (Mensink and Katan 1990). An overreaction occurred, with several cities and state governments imposing bans on

restaurant foods that contain trans fats. Several major food producers switched to trans free alternatives. Alternatives to partially hydrogenated oil were sought. Overall, the outcome has impacted the commodity markets. Credits for the reductions in trans fat is shared by food industry, oil processors and seed developers in developing healthier oils. (Journal of the American Medical Association, Feb 8, 2012).

Oilseed processing technology had no solution to reverse the trend. Consumers were introduced to soybean oil with genetically modified, low linolenic acid concentration by Pioneer, Dupont/Bunge/Monsanto/Cargill, and Iowa State University. The low linolenic acid soybean oil had been shown to produce better tasting fried products retaining desirable flavor in shelf-life testing. However, in many trials by various food manufacturers, the increased stability of these new oils was insufficient to drive a market structure that can accommodate new commodity streams for additional edible oils with trait modification. Some of these oils include ultra low linolenic acid oil, mid oleic acid soybean oil, high oleic acid soybean oil, and high saturated soybean oil.

Other oils may fit the current oil market: mid and high oleic canola oils with reduced linolenic acid content, and mid and high oleic sunflower oils. The low linolenic canola oil met the increased stability requirements for baking and snack food frying. The combined low linolenic high oleic oils are ideally suited to be a substitute for high stability oils required for deep fat frying. Generally, the modified composition of frying oils (Warner 2007) has an undesirable effect on flavor.

1.4 SUBSTITUTION WITH TRAIT-MODIFIED OILS

The goal of biotechnology with respect to food oil is to develop or modify plants to produce desirable characteristics or traits. The focus has been on output quality traits with improved composition of seeds. With dietary oils, the target is to modify the fatty acid composition of the plant oil. Multiple oils have been modified (Box 1.3).

Fats and oils make up a major portion of many finished foods. Consumer oil products are those based on a specific commodity: soybean, corn, canola, cottonseed, sunflower, safflower, olive, and cocoa butter.

Box 1.3 Oils That Have Been Trait-Modified by Plant Breeding and/or Biotechnology

- Low linolenic soybean
- Mid oleic soybean
- High saturate soybean
- High oleic soybean
- High stearodonic acid soybean
- Low linolenic canola
- High oleic, low linolenic canola
- Low saturate canola
- High lauric canola
- Low saturate sunflower
- High oleic sunflower
- Mid oleic sunflower
- High oleic safflower

Consumer expectation is that the label ingredient for a particular oil type is what is in the bottle. Trait identification for a retail oil is not required because of the need for minimum shelf-life of the oil and possibly shelf-life of consumer prepared foods at the table.

Determining performance of oils in formulated foods is much more challenging. Shortening may be prepared in several physical forms: solid shortening, fluid shortening, liquid shortening, and powdered shortening. Oil sales and products may also be in various functional forms such as: all purpose, specialty bakery, donut fry, and bakery spray oils.

Oils formulated for food service frying may be targeted to industrial frying, institutional frying, and fast food frying. The characteristics of the trait-modified oils suitable for frying are:

- low linolenic – moderate stability, high deep fat fried flavor intensity
- high oleic – high stability, low deep fat fried flavor intensity, waxy/plastic flavor
- mid oleic – high stability, high deep fat fried flavor intensity.

Specialty applications for oils may include margarine, spreads, imitation dairy, mayonnaise, salad dressing, confectionery coatings or popcorn seasoning. A majority of trait-modified oils are targeted to be either liquid oils or solid fats dispersed in liquid oils. Yet many foods require a solid or semi-solid fat ingredient for functionality. The liquid oils with high stability can be targeted to frying, consumer/retail oils or as a component of a blend of trait-modified oil. To make an all purpose shortening (more solid), it is based on blending with a trait-modified oil and the addition of a fully hydrogenated hard fat component; 15–25% of the hard fat is blended. A high oleic, low linolenic canola oil may be interesterified to produce shortenings with better melting (Orthoefer 2005). A finished votated shortening blend has the appearance and consistency of a traditional all purpose shortening. Performance in cakes was equivalent to an all purpose shortening based on a hydrogenated soybean oil blended with a cottonseed oil hardstock.

Both physical blends and interesterified oil blends have been formulated into shortenings. Performance of interesterified blends was similar to conventional shortenings. Both chemical and enzymatic interesterification achieved similar positive results.

Use of trait-modified oils in food service frying was investigated by Przybylski (2007). He found that high oleic, low linolenic canola oil (70% plus oleic acid content) was found to have the best frying performance as measured by formation of polar compounds and carbonyl components. The best nutritional quality fried foods occurred when this oil was used. The oil contained only trace trans content (no trans), had a low rate of oxidative deterioration, and received high scores from consumer taste panels. Frying durability could be extended beyond that for partially hydrogenated soybean oil.

1.5 FATS AND OILS – NUTRITION

Most dietary fats are 95–100% absorbed. Fats broken down to monoglycerides and free fatty acids in the intestine are absorbed, then recombined in the intestinal wall. If the carbon chain is longer than 10 carbon atoms, they are transported via the lymphatic system. If the carbon chain is less than 10 atoms, they are transported via the portal vein to the liver where they

are metabolized. Triglycerides, whether from diet or endogenous sources, are transported in the blood as lipoproteins. The triglycerides are stored in adipose tissue until they are needed as a source of calories. Excess calories are stored as fat. The body can make saturated and monounsaturated fatty acids by modifying other fatty acids or by *de novo* synthesis from carbohydrate and protein. Polyunsaturated fatty acids, such as linoleic acid, cannot be made by the body and must be supplied in the diet.

Cardiovascular disease (CVD) is a leading cause of death in the US. These are chronic degenerative diseases often associated with aging. The relationship of dietary fat and coronary heart disease has been examined since the 1950s. Diet affects serum cholesterol and the risk of “heart attack” increases with elevated serum cholesterol levels. Diet modification to achieve lower serum cholesterol levels is recommended. This includes reducing consumption of total fat, saturated fat, trans fats, and cholesterol.

The largest portion of total cholesterol is in the LDL fraction. High density lipoprotein (HDL) cholesterol has been associated with protection against coronary heart disease. A national program was established in the mid-1980s by the National Heart, Lung, and Blood Institute and the National Institutes of Health, to increase public awareness regarding the importance of lowering elevated serum cholesterol levels.

The three major types of dietary fatty acids (saturated, monounsaturated, and polyunsaturated) appear to influence total LDL and HDL differently. Monounsaturated and polyunsaturated fatty acids are cholesterol lowering when they replace significant levels of saturated fatty acids in the diet. Studies have shown that polyunsaturates lower LDL and total cholesterol (Gardner and Kraemer 1995). Monounsaturated fatty acids decrease LDL cholesterol to a greater extent than polyunsaturated fats, while maintaining HDL cholesterol levels (Committee on Nutrition 1992; Mata et al. 1992).

Cardiovascular diseases declined from 1984 to 1994. Specific reasons for this are not known (AHA 1998). Increased public awareness and more effective treatment of heart diseases may have played a role.

Cancer is the second leading cause of death in the US. Cancer is a group of diseases caused by external and internal factors. Many cancers

are related to dietary factors and are believed to be preventable. No markers exist to indicate that a cancer is developing.

Some associations exist between dietary factors such as high fat intake and appearance of cancer at certain sites. A causal relationship has not been established (Ip and Marshall 1996).

Trans fatty acid content of dietary fats and oils is linked to CVD. These have a greater negative effect with respect to coronary heart disease than saturated fatty acids (British Med Journal, 2006). Complete or near avoidance of trans fats may be necessary. The alternatives should be low in both trans fats and saturated fatty acids (British Med Journal, 2006).

Trans fat consumption among US adults has decreased by 58% over the past decade. This coincides with regional bans and government regulation on labeling of trans content.

1.6 MARKETS FOR TRAIT-MODIFIED OILS

Essentially three major markets exist for trait-modified oils:

- consumer/retail
- food service
- food ingredient.

The consumer market consists mainly of bottled oils with specific identity (soybean, cottonseed, corn, canola, sunflower). A major nutritional issue is the fatty acid composition, whether saturated, monounsaturated or polyunsaturated, stability and taste. Stability of consumer/retail oil is not an issue with excellent packaging and controlled distribution.

The food service market is largely performance driven, combined with price concerns. The extreme conditions used in frying impact cost and price. For example, a frying oil with twice the fry life is more economical than using a similar oil with half the fry life. Food service fry oils are a major source of trans fatty acids from partial hydrogenation. Shelf-life of food service fry oils is of less importance since most fried products are consumed shortly after preparation. Of greater concern to

the food service handler is the performance of the oil in the fryer (Przybylski 2007). Food service handlers want a healthy oil, but also one that performs well in the fryer.

Oils as food ingredients may require fry stability or stability during storage before consumption, and stability during processing. The oil component must allow the production of a food of desired appearance, good texture, excellent taste, creaming, etc. Melting points, solids content, lubricity, and moisture barrier properties (spray oils) are among the quality attributes sought (List 2007). Bakery shortenings (all purpose, roll in, bakery margarine), filler fats, fry oil for donuts, meltable fats for dairy replacers (margarines, spreads, coffee creamers) are produced. The combination of hard fats with trait-modified oils by interesterification may substitute for traditional products.

Trait modification for edible oils has seen noted improvement in nutritional content and functionality. This includes reduction in saturated and trans fatty acid content with improved stability, and creation of specific fatty acid profiles for functional foods. The Major factors for determining consumer acceptance of trait-modified oils includes:

- Cost/price vs commodity oil
- Consumer resistance to purchase the better oil because of familiarity
- Supply, availability
- Identity preservation
- Some are genetically modified organism (GMO) oilseeds
- It's a niche marketing product.

1.7 FUTURE OF TRAIT-MODIFIED OILS

Trait-modified oils will continue to improve. The composition of commodity based TMO will assist in satisfying supply, availability, functional products, and healthy formulations. Concepts for trait-modified oils include:

- balance of omega 3, omega 6, and omega 9 fatty acids
- very low saturated fatty acid content
- minor components and performance and nutrition.

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