Methods and Opportunities for Reducing or Eliminating Trans Fats in Foods

This report reviews the methods available to reduce or eliminate industrially produced trans fatty acids from the Canadian food supply. The report considers alternatives to trans fats and possible innovations that might help Canadians achieve the public health objective.

Report prepared for

Market and Industry Services Branch
Agriculture and Agri-Food Canada

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March 31, 2005

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Executive Summary

For some time, Canadians have been learning about the health implications of trans fatty acids produced industrially during oil refining. Trans fatty acids have been implicated as increasing levels of LDL-cholesterol and lowering the beneficial levels of HDL-cholesterol in the blood. A decrease in the consumption of trans fatty acids is being identified as important to lowering the risk of coronary heart disease. Some experts argue that, gram for gram, trans fatty acids pose a greater risk of coronary heart disease than do saturated fatty acids.

This report reviews the methods available to reduce or eliminate trans fats in foods. The report considers alternatives to trans fats and possible innovations that might help Canada achieve the objective. The end result is an analysis, from a technological point of view, as to how ready the Canadian industry is to deal with the possibility of a reduction or elimination of industrially produced trans fatty acids from the Canadian food supply.

Main Players to Address the Issue

The objective to reduce trans fatty acids in foods involves three main players, with differing roles and responsibilities. The challenge is to align the interests and activities of these players with the public health objective.

1. **Food Industry**
   - Requires changes in manufacturing practices.
   - Requires resources to develop innovative processes and products.

2. **Consumers**
   - Be aware of food product choices.
   - Choose healthy foods and lifestyles.

3. **Governments**
   - Be certain of the science, and the intervention strategy.
   - Understand the impacts of any changes implemented.
   - Guide – via regulation, by example, by inducement.
   - Communicate a credible and consistent message.

To substantially reduce or eliminate trans fats from the diet of Canadians, it would seem desirable that most foods sold at retail or by food service establishments be zero or low in trans fats. However, as manufacturers reduce trans fats in food products, the pace of change towards reducing trans fat in the diet will depend on each individual's decision to purchase or not to purchase the new zero or low-trans foods marketed by the food industry.

Properties of Oils and Fats

Oils and fats are the primary source of energy for the body. They are also carriers of flavor and vitamin compounds and contributors to the mouthfeel of food. In manufacturing food, fats perform as a heat transfer medium, lubricant, release agent and texturizing agent. These sensory, functional and nutritional properties of fats and oils are determined by the levels of palmitic (C16:0) and stearic (C18:0) saturated fatty acids, oleic (C18:1) monounsaturated fatty acids (MUFA), polyunsaturated fatty acids (PUFA) (see Figure I) and also trans fatty acids.

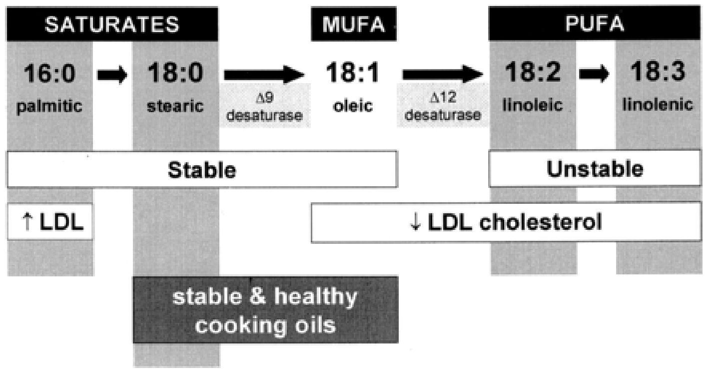

Figure I. Characteristics of Cooking Oils with Degrees of Unsaturation

The melting characteristics of fats determine their usefulness in food products, both in terms of their behavior during processing and during consumption. Increasing the level of saturation increases the melting point of fats, and converts liquid oils into plastic semi-solids or solid fats. Saturated fats are about 10 times more stable than mono-unsaturated oils and fats, 100 times more stable than di-unsaturates, and 1000 times more stable than tri-unsaturates.

Occurrence of Trans Fatty Acids in Foods

Trans fatty acids originate primarily from partially hydrogenated vegetable oils. However, 3 – 8% of the fatty acids in butter, cheese, milk, beef and mutton can also be trans. The latter are produced naturally in animals by the enzymatic hydrogenation of unsaturated fats.

A study by Innis *et al* of the University of British Columbia showed there was significant variability in the trans fat content of 200 foods purchased from retail and food service establishments in 1999. Depending of the food product, the trans fat levels ranged from zero to over 60% of the total fat. Margarines, convenience foods and baked goods showed the highest levels of trans fatty acids in the fat. Hard margarines followed by soft margarines contained the highest levels of trans fat as a percentage of the total food product.

The North American edible oil industry including Canadian firms has made significant progress towards reducing the trans fat contents of foods. Many brand owners are marketing low/zero trans in established and new products. The progress is confirmed in a recent report of several branded snack foods. The analysis of other foods is on-going.

For this report, our inspection of food products in a major supermarket showed that many labels declare lower levels and often zero levels of trans fatty acids compared to the averages reported in the 1999 Innis study. With the food industry's current efforts to reduce or eliminate trans fats in foods, the data reported by Innis *et al* should perhaps now be viewed as historical and not necessarily representative of the trans fatty acid content of foods in Canada in 2005. However, our inspection of food labels suggests that the trans fatty content of hard margarines and some other foods may still be problematic, with some labels declaring ~35% trans fatty acid content in the fat.

Trans Fat Reduction Methods Available to the Industry

There are three main approaches that can be used to reduce or eliminate trans fats in food:

1. Customization of Crop Varieties

- Mutation and transgenic technologies provide the possibility for plant breeders to incorporate a range of fatty acid profiles that are different to the composition of the normal (original) oil in many oilseed species (see Figure II).

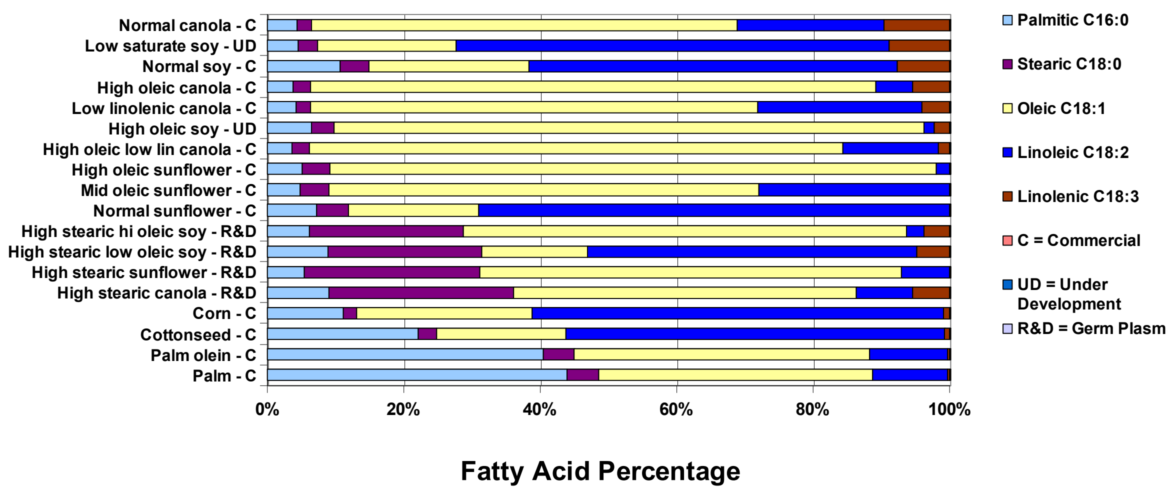

Figure II. Fatty Acid Composition of Vegetable Oils

- Warner has recommended that salad and frying oils be developed with moderate levels of oleic acid (< 80%) and low linolenic acid (< 3%). In addition, saturated fatty acids were recommended to be low (<7-8%) and linoleic acid at least 20-30%. Oils with this profile should have sufficient oxidative stability for use in many salad, frying and spray oil applications and not need light hydrogenation. By avoiding hydrogenation, trans and saturate fatty acid levels are not increased.

- Low linolenic high oleic canola oil genotypes with less than 3% linolenic acid are already in commercial production in Canada. The present varieties however are lower yielding than canola varieties with normal fatty acid composition. This is due to the relatively lower investment that has been made over the past 15 years to breed low linolenic varieties and the fewer generations of plant improvement compared to those with normal fatty acid composition. Low linolenic genotypes in soybean are in the early stages of commercialization in the US.

- With the superior quality and expanding demand for low linolenic genotypes for food manufacturing and food service, the Canadian plant biotechnology industry might be expected to increase its investment in breeding for low linolenic genotypes adapted for Canada. The industry might also consider investing to develop high stearic genotypes targeted for the solid fat markets. Both types of oils should reduce the need for hydrogenation and resulting production of trans fatty acids. However, the high stearic genotypes are synonymous with high staturates.

2. Modification of Fatty Acid Composition by Processing

There are six main processing techniques available to the edible oil industry to reduce trans fatty acids as the chemical and physical of oils and fats are modified for food use.

- Hydrogenation – mature technology, current practice of the industry.
  - ✓ For products needing the melting properties of a partially hydrogenated basestock, zero trans is not likely to be possible with light hydrogenation.
  - ✓ For products that must have the melting characteristics of a plastic or solid fat, complete hydrogenation of a canola or soybean oil will result in a zero trans stearine fat which is almost 100% saturated.
- Blending of basestocks – mature technology, current practice.
  - ✓ Zero or low trans can be produced by blending various basestocks.
  - ✓ Difficult to get the desired melting properties in the plastic blended fat.
- Fractionation – mature technology, with some potential for more use in Canada.
  - ✓ Widely used in palm oil processing in other countries. Results in unsaturated palm olein and saturated palm fractions with useful melting properties.
  - ✓ Process has been demonstrated with experimental high stearic soybean oil.
- Use of Saturated Fats – mature technology, but limited alternatives for Canada.
  - ✓ Domestic – fully hydrogenated canola and soybean C18:0 stearine.
  - ✓ Domestic – animal fats – tallow and lard.
  - ✓ Imported – tropical oils and fats – palm, coconut, babasu, etc.
- Chemical Interesterification – mature but improving technology.
  - ✓ Proven track record in Europe and some use in US and Canada.
  - ✓ Range of consistencies and melting properties possible for zero or low trans margarine, shortening and confectionary fats.
- Enzyme-assisted Interesterification – emerging technology, with great potential.
  - ✓ Enzymes can be highly specific, providing for more control of the reaction and lower processing temperatures than chemical catalysis.
  - ✓ Lipolase™ – produced by Novozyme A/S by fermentation of an *Apergillus orzyae* strain genetically modified with a *Thermomyces lanuginosus* lipase gene.
  - ✓ Economics of interesterification improved greatly with immobilization and reuse of the Lipolase enzyme.
  - ✓ Novozyme / De Smet now marketing a low trans process with lower capital and operating costs than hydrogenation and chemical interesterification.

3. Food Reformulation

One strategy for reducing trans fatty acids is to decrease the overall fat content in foods. Fat replacement will become very important if it is determined that the levels of saturated fats should not increase as trans fats are reduced. With few exceptions, fat replacement will require product reformulation in order to achieve the desired properties in the processed food. When fat is removed from most products, bulking is required. In addition, other functionalities such as melting or lubricity must be considered.

Fat replacers are ingredients which mimic the functionality and sensory properties of fat, but contribute fewer calories. Fat replacers can be based on lipid, protein, or carbohydrates. Selection of suitable fat replacers requires a solid understanding of the food system in question and careful weighing of the advantages and disadvantages of each product. In many cases, a blend of ingredients offers the best solution for fat reduction. It is worthy to note that some food ingredients that might be useful as fat replacers are not approved for use in Canada.

Initiatives to Reduce Trans Fatty Acids In Foods

1. Investment

Solutions to reduce trans fatty acids in foods will require investment for replacement technologies and development of new processes and products. These avenues call for public and private investment in R&D, technology transfer and demonstration, and capital investment. For each product, there are choices to be made whether the technical solution should be made in Canada or purchased from abroad. When considering public investment in R&D, it is suggested that public funds are best applied where the R&D provides the Canadian industry with lasting competitive advantage.

2. Public Awareness and Education – Fats & Oils

While the public is increasingly aware of trans fats, it is perhaps not sufficiently aware of the range of nutritional choices available and that many foods require the physical and chemical properties provided at present by saturated or trans fats. It appears there may be need of more public education about saturated fats – and that these might be nutritionally acceptable or at least tolerated at some level in some foods.

3. Health Benefits of Low / Zero Trans Fat Products

Many of the techniques being adopted by the industry to replace trans fats rely on the increased use of C16:0 palmitic and C18:0 stearic saturated fatty acids. Validation of the nutritional merits of these new palmitic and stearic saturated fat formulations as replacements for trans fatty acid formulations seems warranted.

While trans fats are a hot topic today, most trans mitigation strategies being implemented do not reduce caloric intake. It has been suggested that obesity mitigation could be a bigger issue for everyone to deal with than trans fat mitigation.

4. Change the Composition of Oils and Fats - Timeframe

- Retail salad & cooking oils, salad dressings
  - ✓ Native canola, soybean & sunflower oils are naturally in low trans fats.
  - ✓ Very small amounts of trans fat produced during deodorization.
  - ✓ Additional trans fat if, for example, soybean oil is lightly hydrogenated.
  - ✓ Low linolenic canola oil is available today, but has no marketing advantage in Canada to normal canola salad oil when sold as a retail packaged salad oil.
- Margarines and spreads
  - ✓ Soft margarines – low trans available today. Low trans soft margarine products exhibit a wide range of polyunsaturated fatty acid content.
  - ✓ Hard margarines – still high trans fat. Low trans possible if processors ignore functionality and cost. New products possible in a 1 – 3 year timeframe, but likely to contain high levels of saturated C16:0 and/or C18:0 fatty acids.

- Frying oil – food service and quick service
  - ✓ Heavy duty frying requires stable fats.
  - ✓ Low linolenic / high oleic canola & sunflower being adopted, but at higher cost and some reduced functionality /sensory properties.
  - ✓ Low linolenic soybean entering US pipeline. A Dupont high oleic soybean trait has been approved in Canada.
  - ✓ 1 – 3 years for product development with existing oils.
  - ✓ 4 – 8 years for low linolenic soybean oil, if pursued by the industry.
- Industrial frying and food processing.
  - ✓ Low linolenic / high oleic canola and sunflower available today for snack frying, with acceptable functionality and sensory properties.
  - ✓ Potato chips, tortilla chips, frozen french fries, etc. converting to low trans. See USDA 2004 report confirming the progress.
  - ✓ Doughnut frying and spray oils – still a challenge for functionality.
  - ✓ 1 – 3 years for product development with existing oils.
  - ✓ 4 – 8 years for low linolenic soybean oil, if pursued by the industry.
- Baking shortenings.
  - ✓ Wide range of food product specific functionalities required.
  - ✓ Melting characteristics of the plastic fats critical and tied to the trans and saturate fat contents of the basestocks.
  - ✓ Fractionated and interesterified fractions are possible replacements for trans.
  - ✓ Formulation challenge to develop zero or low trans replacements for all purpose shortening, emulsified shortenings, and pastry roll-ins where specific functionalities required.

Closing Remarks

Reducing or eliminating trans fats will be transforming for the Canadian as well as the global food industry. There are no drop-in solutions that can easily be applied at just one level of the industry in order to effect total change. The transformational change needed is systemic and requires a variety of technical solutions, many players and the support of consumers.

The industry has made considerable progress to reduce trans fats in many products, and is striving to bring forward zero or low trans fat solutions for all food products. There are challenges that remain, but these are surmountable with investment, time and learning.

It is significant that the leading technologies result from the convergence of mutation and transgenic plant breeding, innovative process engineering and the latest in food science and product formulation. Some of basic nutrition research and plant breeding supporting the solutions that are being advanced have been under study for as long as 30 years. The investment in plant breeding has been significant, initially by public institutions, and commencing about 15 years ago, increasingly by industry in Canada and elsewhere.

Equally important, many of the core technologies beginning advanced appear to have commercial potentials for new products and new foods that might address issues far beyond the trans fats problem. The long-term benefits of these innovations are possibly greater than those identified at present for trans fat mitigation.

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1. Introduction

For some time, Canadians have been learning about the health implications of edible oils and fats; in particular, trans fat, or trans fatty acids (TFA), which are produced industrially during oil refining. The main components of fats and oils are triacyl glycerides (TAGs). They consist of three fatty acids attached to a glyceride backbone through ester linkages. Oils and fats containing saturated and unsaturated fatty acids are obtained from both animal and plant sources. Liquid unsaturated oils are easily hardened by a catalytic reaction called hydrogenation. When oils and fats are not fully hydrogenated, the reaction yields a mixture of cis and trans forms of the unsaturated fatty acids in the TAGs.

Many Canadians are now championing the reduction or elimination of trans fatty acids in foods as they have been implicated as increasing levels of LDL-cholesterol and also lowering the beneficial levels of HDL-cholesterol in the blood. Some experts argue that, gram for gram, TFAs pose a greater risk of coronary heart disease than do saturated fatty acids. The decrease in the consumption of trans fatty acids therefore is being identified as important to lowering the risk of coronary heart disease.

This report reviews the methods available to the Canadian industry to reduce or eliminate trans fats in foods. The report also evaluates alternatives to trans fats and possible innovations that might help Canada achieve the objective. The end result is an analysis, from a technological point of view, on how ready the members of the Canadian industry are to deal with the possibility of a reduction or elimination of industrially produced trans fatty acids from the Canadian food supply.

In this report, the Canadian food industry is defined so as to encompass plant geneticists, seed merchants, oilseed growers, oilseed crushers, edible oil refiners, food manufacturers, food service and food retailers.

2. Background

2.1 Food Choices and Public Health Objectives

A public health objective to reduce or eliminate the consumption of trans fatty acids requires that Canada's food industry respond with changes in practice and innovative products so that the objective is reached. Achieving this objective however, also requires that Canadians be aware of the food product choices available to them, and that they choose to buy foods with reduced or zero levels of trans fats.

Each person's decisions on which foods to buy involve many factors. In addition to providing basic nutrition in products that are safe, successful food products must be affordable and serve Canadians' diverse preferences for food and lifestyles.

The Canadian grocery and food service industries offer an amazing choice of foods. Canadians are truly fortunate to have such a plentiful and economical food supply. With the appropriate selection of foods along the lines of Canada's Food Guide for Healthy Living[1], Canadians are generally able to meet their basic nutritional needs very well. However, continuing improvements to the health and wellness of Canadians are desirable and food choices have a role to play in improving the health status of Canadians.

Canadians buy food regularly from food stores and food service establishments. There is strong evidence that consumer needs influence food suppliers.[2] Regulatory initiatives, consumer and political advocacy, professional food science information statements[3], journalism[4] and publicity related to legal actions[5, 6] have all been important in bringing the trans fat issue to the forefront of public attention in Canada and the United States. The result is that many companies in Canada are working to eliminate or reduce trans fat from their food products.[7]

> ***Observation:*** *Consumers elect every day whether they are going to buy specific foods and from which firm or brand owner. Individuals can choose to not purchase particular foods.*
>
> *To meet the public health objective to substantially reduce or eliminate trans fats from the diet of Canadians, it may be desirable that all foods sold at retail or offered by food service establishments be zero or low in trans fats. However, new and existing food products reformulated to be zero or low trans fat will need to have acceptable sensory properties, be competitively priced, and offer value for the dollar spent.*
>
> *As edible oil refiners convert their manufacturing processes to reduce or eliminate trans fats from their products, the pace of change towards reducing trans fat in the diet will depend on each individual's decision to purchase or not to purchase the new zero or low-trans foods brought to the market by the food industry.*

2.2 Canada's Food System

The manufacturing of food is complex and technically sophisticated. There is intense competition amongst firms at every level of the food business and the profit motive is strong.

Canada's food supply starts with the farm production and harvesting of agricultural and fishery products. Food manufacturers purchase both domestic and imported raw materials and ingredients and process these into safe and nutritious food products. The food processing technologies used are sophisticated and capital intensive. The approaches for distribution, marketing, advertising and selling food at retail and food service are also complex and capital intensive.

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1 Health Canada. Review of Canada's Food Guide to Healthy Eating and Related Dietary Guidance. http://www.hc-sc.gc.ca/hpfb-dgpsa/onpp-bppn/food_guide_e.html
2 Food and Consumer Products of Canada. Healthy Active Living. How our industry is helping Canadians adopt a healthy active lifestyle. http://www.fcpmc.com/issues/hal/index.html
3 Institute of Food Science & Technology. Trans Fatty Acids (TFA) Information Statement, replacing the version dated 23 June 1999. November, 2004 http://www.ifst.org/hottop9.htm
4 TranFAT. http://www.ctv.ca/generic/WebSpecials/transfat/index.html
5 The Oreo Case. http://www.bantransfats.com/theoreocase.html
6 McDonald's in court over trans fats. http://www.foodnavigator.com/news/news-NG.asp?id=53470
7 Food and Consumer Products of Canada. Companies removing trans fat. http://www.fcpmc.com/issues/hal/transfat.html

Industry players from the plant genetics company, seed merchant and primary oilseed producer through to retail and food service are part of a food supply chain (Figure 1). The concept of a food chain implies that individuals and firms at different levels of production and distribution develop linkages and collaborate rather than work independently or in isolation from others in the industry. In value chain environments, firms still compete, but often the competition is between participants in parallel value chains.

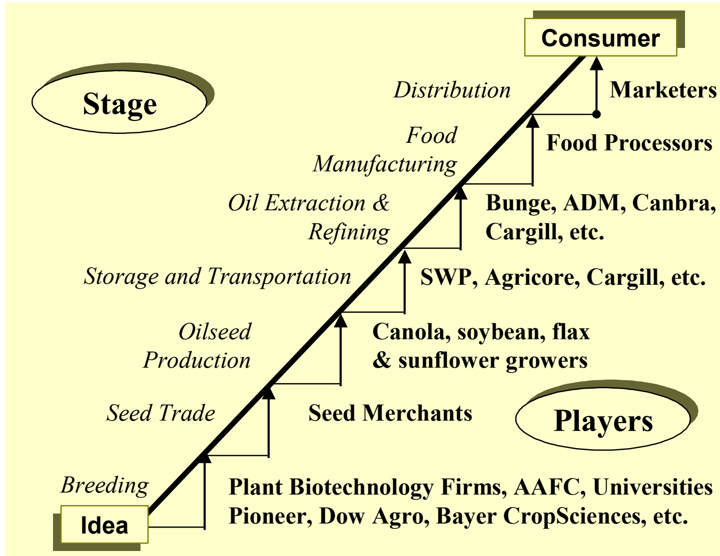

Figure 1. Edible Oil Value Chains

At almost every juncture of the domestic food value chain, raw material inputs are produced and can be purchased from Canadian suppliers. Canada however does not produce or is not a least cost supplier of all the oils and fats needed by the industry. Canada produces surpluses of canola and canola oil, so these are exported. The industry at every level of the value chain is conscious of international competition, considering both exports and imports.

> ***Observation:*** *Individual firms have important roles to play in helping Canadians achieve the objective to reduce or eliminate trans fat from their diets. However, it seems that firms or value chains acting independently cannot by themselves achieve this public health objective. The objective requires collective action by all participants in the industry, in ways that are feasible for each and cost competitive internationally.*

Firms in the food business are constantly seeking to strengthen their affiliation with customers. Product branding and relationship building are key success factors for many companies. Firms also develop competitive advantage in many other ways - including innovation and by being first-movers anticipating consumer, technology and regulatory trends.

> ***Observation:*** *The trans fat objective should provide strategic business opportunities for innovative firms with the critical mass of technology, formulation, marketing and investment capital to be first movers and launch new zero or low trans products.*

2.3 Function of Oils and Fats in Food

Oils and fats fulfill numerous functions in food processing and food products. As food ingredients, oils and fats are:

- A primary source of energy in the body. Fat serves as the body's store of energy.
- Carriers of flavor compounds, and thus heighten the flavor of food.
- Carriers of nutritionally significant fat-soluble compounds such as vitamin E.

- Contributors to the mouthfeel of food. Oils and fats act as lubricants to provide a smooth texture to numerous products – such as chocolate for example.

The sensory, functional and nutritional properties of fats and oils are determined by the levels of palmitic (C16:0) and stearic (C18:0) saturated fatty acids, oleic (C18:1) monounsaturated fatty acids (MUFA) and polyunsaturated fatty acids (PUFA) in the various types of oils (Figure 2).

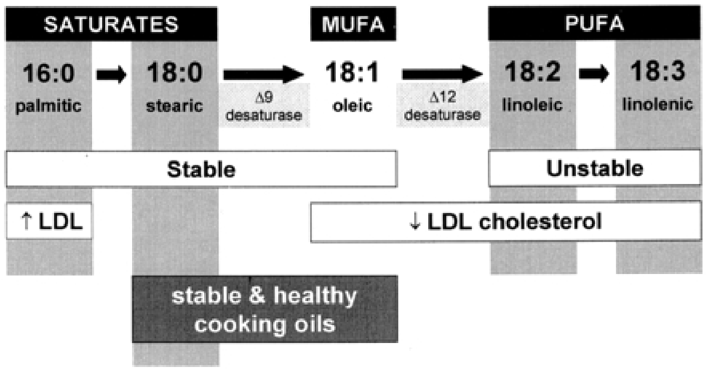

Figure 2. Characteristics of Cooking Oils with Degrees of Unsaturation[8]

Plant breeding is widely used to modify the fatty acid compositions of oilseeds. In canola[9] and sunflower[10], levels of 85 – 90% oleic acid are known, and in sunflower produced commercially in several countries. Oils with very high oleic and low linolenic acids became breeding targets because it was expected there would be less deterioration of the oil in frying operations. While this proved to be true, when fried foods such as potato chips, tortilla chips and french fried potatoes were prepared in very high oleic canola or sunflower oils, they were found to have less deep fried flavor than in oils with moderate or low oleic acid.[11]

Based on this research, Warner has recommended that salad and frying oils be developed with moderate levels of oleic acid (not more than 80%) and low linolenic acid (not more than 3%). In addition, saturated fatty acids were recommended to be low (<7-8%) and linoleic acid at least 20-30%.

Low linolenic canola oil genotypes with less than 3% linolenic acid are already in commercial production in Canada. This oil does not need "brush" or light hydrogenation to increase the oxidative stability of the liquid oil for its use as salad, frying and spray oils. Similar low linolenic genotypes in soybean are in the early stages of commercialization in the US.

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[8] Qing Liu, Surinder Singh, and Allan Green. 2002. http://www.maizegdb.org/mnl/58/76jellum.html
[9] Wong, Raymond S. C.; Beversdorf, Wallace D.; and Grant, Ian. Production of Improved Rapeseed Exhibiting an Enhanced Oleic Acid Content. EP 0323753 B1, 1994.
[10] Early Russian research into increasing oleic levels in sunflower used mutagenesis to form Pervenets sunflowers with elevated oleic acid levels. The seed is available to the public and much of the high oleic sunflower germplasm today descends from that research. Many high oleic sunflower seed varieties have subsequently been described in patent literature.
[11] Warner K., Neff W.E., Byrdwell W.C., Gardner H.W. Effect of oleic and linoleic acids on the production of deep-fried odor in heated triolein and triolinolein. J Agri Food Chem 49 :899 –905, 2001.

Linolenic acid is considered to be essential fatty acid by some nutritionists, and thus 0% linolenic acid in canola and soybean oils may be an undesirable target. Flax oil contains 57% linolenic acid and is commercially available as a salad oil and dietary source of linolenic acid.

> **Observation:** *Low linolenic canola varieties developed by Dow AgroSciences Canada Inc[12], Cargill Specialty Canola Oils[13] and Saskatchewan Wheat Pool[14] meet Warner's recommended profile for a liquid salad and frying oil. Note: in commerce, low linolenic varieties are also called high oleic, but oleic contents are at ~75 – 80%.*
>
> *Low linolenic canola and soybean oils have better oxidative stability compared to normal canola or soybean oils. In oils with comparable levels of low linolenic acid, oils with higher oleic contents are more stable than oils with higher linoleic acid. The low linolenic high oleic oils do not require hydrogenation for use in many frying applications and in some food processing, and are excellent zero-trans substitutes for lightly hydrogenated soybean oil. And with less than 7% saturated fatty acids, low linolenic high oleic canola oil, like normal canola oil, is good for the heart and qualifies for a low saturate label claim. As linolenic acid is an essential fatty acid, the reduction in linolenic acid may be a drawback to these high stability salad and cooking oils.*

In manufacturing food, fats perform as:

- A heat transfer medium.
- Lubricant.
- Release agent.
- Texturizing agent.

These functions rely on the physical and chemical properties of oils and fats.

The fact that oils and fats do not boil, even at high temperatures, makes them ideal heat transfer media in manufacturing processes where food materials have to be heated to temperatures above the boiling point of water. In food systems, oils and fats are stable to acids and bases, but are susceptible to oxidation. Oils and fats with increasing un-saturation are more susceptible to oxidation than oils and fats that are more saturated. For example, saturated fats are approximately 10 times more stable than mono-unsaturated oils and fats, 100 times more stable than di-unsaturates, and 1000 times more stable than tri-unsaturates.

The melting characteristics of fats determine their usefulness as ingredients in many food products, both in terms of their behavior during processing and during consumption. Increasing the level of saturation increases the melting point of fats, and converts liquid oils into plastic semi-solids or solid fats.

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[12] Lanuza, Juan Enrique Romero and John Lawrence Sernyk. Oil of *Brassica* napus. US Patent 6169190, 2001.
[13] DeBonte, L. R., Willie H. T. Loh, and Zhegong Fan. Canola oil, with reduced linolenic acid. US Patent 6,689,409 B2, 2004.
[14] Saskatchewan Pool. 2005 Seed Guide. SP Craven. http://www.swp.com/Seed/pdf/Pool_SeedCat05_canola-spec.pdf

The number of TAGs in a fat or oil is large as they typically contain many different fatty acids of differing chain length and degree of unsaturation, and each fatty acid can occupy any of the three positions on the triglyceride backbone. When trans fatty acids are produced upon hydrogenation, the number of TAGs increases further. Each TAG has its own unique melting temperature. As a result, fats melt over wide ranges of temperatures. It is the melting behavior of TAGs that defines the plasticity and functionality of fats.

Trans fatty acids have melting points well above those of monounsaturated liquid oils, but below those of saturated fats. As the melting range of trans fats is near body temperature, they contribute to a smooth mouthfeel.

> ***Observation:*** *Manufacturers produce fats to have the specific stability and melting characteristics needed for the fat of the final food product. Reducing the degree of unsaturation results in desirable changes in the melting characteristics and oxidative stability of fats. When trans fatty acids are produced, they broaden the range of physical properties available for food formulation. Research and product testing will be needed for the industry to find low-trans replacements with the functionalities that are lost if trans fats are removed from foods requiring shortenings.*

2.4 Occurrence of Trans Fats in Food

Trans fatty acids in the diet originate primarily from partially hydrogenated vegetable oils. However, about 3 – 8% of the fatty acids in butter, cheese, milk, beef and mutton can also be trans.[15] The latter trans fatty acids are produced naturally in animals by the enzymatic hydrogenation of unsaturated fats.

Back in the 1960s, formulations of "modern" Dutch margarines and shortenings were reported to contain up to 50% trans fatty acids.[16] In those days, the Dutch margarines contained trans fatty acids from both hydrogenated vegetable and hydrogenated fish oils. With changes in the processing and formulation from 1980 to 1994, the trans fat contents of Dutch margarines decreased from 20% to ~5%.[17]

Ratnayake *et al* reported on the fatty acid composition of foods in Canada in 1993.[18] A later study by Innies et al of the University of British Columbia provided data on the trans fat content of over 200 foods available in Vancouver grocery and food service establishments in the late 1990s.[19] This work showed there was significant variability in the total fat and trans fat content of foods (Table 1). The variability in the trans fat contents was seen to limit the accuracy of dietary trans fat estimates when analysis is made using nutrient databases.

The trans fat content of the fat in the foods of the 1999 Innis study ranged from almost zero to over 60%, depending of the specific food product. Margarines, convenience foods and baked goods made with shortening showed the highest levels of trans fatty acids in the fat.

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15 Pfalzgraf, A., Timm, M., and Steinhart, H. "Gehalte von *Trans*-Fettsauren in Lebensmitteln". Z. Ernahrungswiss. 33: 24-43, 1994.
16 Rice, E.E. Weiss, T. J. and Mattil, K. F. "Composition of modern margarines". J. Am. Diet Assoc. 41: 319 – 322,1962.
17 Zock, P. L. and M. B. Katan. Can. J. Physiol. Pharmacol. 75: 211 – 216, 1997.
18 Ratnayake, W. M. N. et al., "Fatty Acids in Some Common Food Items in Canada", J. Am. Coll. Nutr. 12(6):651-660, 1993.
19 Sheila M. Innis, Timothy J. Green and Thomas K. Halsey. "Variability in the Trans Fatty Acid Content of Foods within a Food Category: Implication for Estimation of Dietary Trans Fatty Acid Intakes". J. Amer. College of Nutrition, Vol. 18, No. 3, 255 – 260, 1999.

Hard margarines followed by soft margarines contained the highest levels of trans fat as a percentage of the total food product.

Table 1. Fat and Trans Fat Content of Selected Food Products

Food Product	Number of Samples	Total Fat g/100 g food		Trans Fatty Acid % of fat		Trans Fatty Acid g/100 g food	
		Average	Range	Average	Range	Average	Range
Breakfast cereals	11	3.0	0.3 – 9.5	4.2	0.2 – 24.3	0.1	0.0 – 1.1
Whole bread	8	2.2	1.9 – 3.1	18.5	1.3 – 34.9	0.4	0.0 – 1.0
Whole wheat bread	8	2.7	1.9 – 3.5	15.6	1.0 – 36.3	0.5	0.0 – 1.3
Granola bars	7	11.5	5.1 – 17.0	11.3	5.1 – 21.7	0.9	0.1 – 1.4
Meat patty	4	16.4	14.0 – 45.9	6.8	5.6 – 9.6	1.1	0.8 – 1.4
Muffins	7	9.4	1.7 – 13.1	11.2	1.7 – 36.2	1.3	0.1 – 4.0
Potato chips	6	25.1	21.9 – 30.6	5.9	0.4 – 25.3	1.4	0.1 – 5.7
Peanut butter	2	43.5	41.1 – 45.9	4.1	1.6 – 6.6	1.9	0.7 – 3.1
French fries	16	5.8	3.2 – 10 9	37.7	4.9 – 56.9	2.1	0.2 – 3.7
Cake mixes	3	7.6	4.8 – 9.2	29.6	28.7 – 30.1	2.3	1.4 – 2.8
Chocolate bars	9	23.6	13.4 – 30.9	9.2	0.1 – 35.9	2.3	0.0 – 8.3
Soups	11	8.3	0.6 – 17.8	22.4	1.1 – 51.6	2.6	0.0 – 9.1
Croissants	3	16.6	13.5 – 18.5	18.1	5.5 – 40.9	3.0	0.7 – 7.6
Cookies	19	16.7	3.3 – 22 9	23.0	1.4 – 45.7	3.5	0.3 – 8.1
Sauces and gravy	16	8.7	0.4 – 38.3	33.2	1.7 – 60.3	3.6	0.0 – 23.1
Breaded chicken	8	13.4	6.6 – 18.1	27.4	11.9 – 56.7	3.7	0.9 – 6.9
Pie shells	6	18.3	9.4 – 26.5	25.8	1.9 – 45.6	3.8	0.5 – 8.7
Donut	13	13.5	3.9 – 21.3	29.6	3.9 – 42.7	3.9	0.5 – 7.8
Croutons	3	15.7	11.6 – 19.1	41.9	22.9 – 51.6	6.3	4.4 – 8.5
Crackers	14	15.3	2.1 – 27.4	40.3	23.5 – 51.3	6.4	0.7 – 12.9
Margarine, soft	14	ND	ND	16.8	1.1 – 44.4	16.8	1.1 – 44.4
Margarine, hard	14	ND	ND	39.8	31.1 – 44.6	39.8	31.1 – 44.6

ND. Not determined, assumed to be 100% for the fatty acid analysis.
Source: from Innes et al, 1999.

The North American edible oil industry has made significant progress in reducing the trans fatty acid contents of foods. Many brand owners are aggressively advertising low/zero trans in established and new products. The progress is confirmed in a recent report by the USDA of several branded snack foods.[20] The analysis of other foods is presently underway.

Our inspection for this report of food product in a major supermarket showed that many labels declare lower levels and often zero levels of trans fatty acids compared to the averages reported in the 1999 Innes study. However, the trans fatty content of hard margarines and some other foods still seems to be problematic, with some labels declaring ~35% trans fatty acid content in the fat.

> ***Observation:*** *With the North American food industry's current efforts to reduce or eliminate trans fats in foods, the data reported in Table 1 from the 1999 Innis study should be viewed as historical and not necessarily representative of the trans fatty acid content of foods in Canada in 2005.*

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[20] Khan, M., P. Pehrsson, L. Lemar, B. Teter, and J. Sampugna. Changes in Trans Fatty Acid Profiles for Selected Snack Foods in the USDA National Nutrient Database for Standard Reference. 2004.
http://www.nal.usda.gov/fnic/foodcomp/Data/Other/EB04_transSnack.pdf

2.5 Nutritional Implications of Trans Fat in Food

There has been always a clear connection between fat and obesity, both in terms of the language and causality. As North American and European populations became more affluent and more sedentary, a substantial portion of the populations in both regions became overweight and obese. It was also increasingly clear that increased incidence of cardiovascular disease was linked to obesity and likely, to the increased fat content of the diet.

In the 1960's and 70's, the primary sources of cholesterol in the diet were animal fats. As research showed that cholesterol deposits were linked to cardiovascular disease, the need to decrease the cholesterol content of the diet gained popular acceptance. As a result, there was increasing interest to find alternatives, which provided the same food functionality as traditional animal products, but which had little or no cholesterol. This led to significantly increased demand for vegetable oils, at a time when vegetable oils were inexpensive but of rather poor quality when compared to traditional animals fats.

After hydrogenated vegetable based solid fats were developed, a market battle began between butter versus margarine and lard and tallow versus vegetable shortening. With evidence of cholesterol being a culprit in cardiovascular disease, margarine and vegetable shortening technologies improved rapidly driven by public demand and market share increases. All vegetable oils are cholesterol-free, and thus vegetable oil manufacturers aggressively sought to displace cholesterol-containing animal fats from the market. Hydrogenation was the core technology supporting this change, and the increased presence of trans fats in the food supply was a direct result.

There were early research reports that saturated fats were similar to cholesterol in their effect on cardiovascular disease, and that their replacement with polyunsaturated oils had significant health benefits. Some indications also emerged that the metabolism of trans fatty acids was different from that of cis isomers or the natural forms of the same fatty acids.

A number of researchers believed that trans fats behaved like saturated fats in the body. Accordingly research and development programs initiated in Canada and elsewhere in the mid 1970's sought to:

- Modify the composition of vegetable oils through mutation and transgenic plant breeding and eliminate the requirement to hydrogenate liquid oils for specific food applications.
- Reduce or eliminate trans fat production during hydrogenation.
- Eliminate partially hydrogenated fats from food products.

When concern was expressed that trans isomers have undesirable long-term effects, the Canadian government set up an interdisciplinary taskforce to review the effect of trans isomers in margarine. The "Report of the Ad Hoc Committee on the Composition of Special Margarines" published in 1980 reviewed the health aspects of trans fatty acids.[21] The committee found no solid scientific evidence that trans fats had negative health effects but did recommend regulatory restrictions on the level of trans fats in margarine and shortening. An

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[21] Minister of Supply and Services Canada. "Report of the Ad Hoc Committee on the Composition of Special Margarines". Ottawa. 1980.

American study five years later by the National Science Foundation concluded that trans isomers present no health risk *per se*, the observation being that trans fats are metabolized as if they are saturated fats.[22]

The edible oil industry has used hydrogenation since the 1920's to harden oils. To be sure that the industry would not be caught on the wrong side of a health issue, Thomas Applewaithe, a researcher from Kraft Foods (which was selling both dairy products and hydrogenated oil products), reviewed the scientific research published on the topic to 1981, and concluded that there was no scientific evidence to indicate that trans fats posed any short or long risk to human health.[23,24] During his career, Applewaithe was also President of the American Oil Chemists' Society and Chairman of the National Association of Margarine Manufacturers' Technical Committee. A history of soy oil hydrogenation and research on the safety of hydrogenated vegetable oils to the 1980s is published on the Internet by the Soy Centre. [25]

As a result of the various reports to the mid-1980s, concerns about trans fatty acids by the public and food manufacturers subsided for a time. However, research of the nutritional implications of trans fats, saturated fatty acids and unsaturated fatty acids continued.

During the 1980s, when the American soybean industry faced the rapid incursion of cheap Malaysian palm oil into the American and European edible oil markets, public attention was focused to the potential harmful effect of saturated fats. The soybean oil industry mounted significant pressure to reduce the use of palm oil, which is high in saturated fats. The industry managed to convince the US Congress to mandate the requirement that "tropical oils" be declared on food product labels, thereby motivating manufacturers to eliminate these oils from their food products.[26] Declarations of saturated and trans fats from non-tropical sources were not required.

In 1990, two Dutch researchers, Mensink and Katan published the results of a carefully conducted experiment on 34 women and 24 men in the Netherlands, comparing solid diets with differing contents of oleic (cis C18:1), elaidic (trans C18:1), and saturated (C12-C16) fatty acids.[27] In comparison with oleic acid, C18:1 trans fatty acids were found to raise LDL cholesterol, although not by as much as saturated fatty acids, and to decrease HDL cholesterol. The LDL/HDL cholesterol ratio was higher with the trans fatty acid diet than with the saturated fatty acid diet. This research provided the first clear evidence that trans fatty acids have an undesired effect that may be directly linked to increased probability of cardiovascular disease. These and other studies prompted a further round of more focused research to

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[22] National Science Foundation. "Health Aspects of Dietary *Trans* Fatty Acids". Federation of American Societies for Experimental Biology, Bethesda, Maryland. 1985.

[23] Hunter, J. E. and T. Applewhite, "Isomeric Fatty Acids in the US Diet: Levels and Health Perspectives", Am. J. Clin. Nutr. 44:707-717, 1986.

[24] Hunter, E. J. and T. H. Applewhite, "Reassessment of *Trans* Fatty Acid Availability in the US Diet", Am. J. Clin. Nutr. 54:363-369, 1991.

[25] Soyfoods Center. History of Soy Oil Hydrogenation and of Research on the Safety of Hydrogenated Vegetable Oils. A Special Report on the History of Soy Oil, Soybean Meal, & Modern Soy Protein Products. A chapter from the unpublished Manuscript, *History of Soybeans and Soyfoods: 1100 B.C. to the 1980s,* by William Shurtleff and Akiko Aoyagi. http://www.thesoydaily.com/SFC/MSPproducts501.asp

[26] Tropical Oils: Status of the Storm. http://www.foodproductdesign.com/archive/1995/0595ap2.html

[27] Mensik, R. P. and M. B. Katan. "Effect of dietary *trans* fatty acids on high-density and low-density lipoprotein cholesterol levels in healthy subjects." New Eng. J. of Med. 323: 439-445, 1990.

elucidate the effects of trans fats, to find low trans alternatives, and to define the metabolic pathways that create the undesirable health effects.

In 1994, a FAO/WHO joint expert consultation on the role of dietary fats and oils in human nutrition recommended that food manufacturers reduce the levels of trans fatty acids in their products.[28]

In the past 10-15 years, the public's understanding of the existence of low density lipoproteins (LDL or "bad cholesterol") and high density lipoproteins (HDL or "good cholesterol") increased sufficiently to realize the potential harm of increasing LDL, reducing HDL, and increasing the LDL to HDL ratio.[29,30] As trans fats do not behave exactly like saturated fats and decrease HDL and increase LDL simultaneously, it has been interpreted that trans fats might be more harmful than saturated fats. The exposure by the media of the widespread presence of trans fats in foods resulted in public pressure ranging from requesting the requirement for labeling of trans fats to the complete ban of all trans fats in food.

3. Trans Fat Reduction Methods Available to Industry

3.1 Customization of Crop Varieties

3.1.1 Genetically Modified Fatty Acid Compositions

Modern mutation and transgenic technologies have opened the possibility for plant breeders to incorporate a range of fatty acid oil profiles and other traits of economic importance into oilseed crops.[31, 32,33,34] New fatty acid profiles that are fundamentally different to the composition of the normal (original) oil have been identified in many oilseed species (Figure 3).

Canola was developed by Canadian plant breeders in the 1960s to improve the quality of the original rapeseed. Canola is low in the C22:1 erucic fatty acid and low in glucosinolates. The latter reduce the nutritional value of the canola meal remaining after oil extraction. Normal canola oil contains 9% - 11% linolenic acid (C18:3), which is desirable nutritionally, but which has a negative impact on the oxidative stability and flavor of some foods processed using canola oil. Canola oil delivers additional health benefits by being low in saturated fatty acids. It is the only salad oil sold in the retail market with < 7% saturated fatty acids.

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[28] WHO/FAO. "Fats and oils in human nutrition: Report of a joint expert consultation FAO Food and Nutrition paper 57 Rome." 1994.
[29] Hu, F. B., M. J. Stampfer, et al. "Dietary fat intake and the risk of coronary heart disease in women." New Eng. J. of Med. 337: 1491-1499, 1997.
[30] Asherio, A., M. B. Katan, et al. "Trans fatty acids and coronary heart disease." New England Journal of Medicine 340: 1994-1998, 1999.
[31] Röbbelen G. Mutation breeding for quality improvement. A case study for oilseed crops. Mutation Breeding Review 6:1-44, 1990.
[32] Davies, H.M. Engineering new oilseed crops from rapeseed. p. 299-306. In: J. Janick (ed.), Progress in new crops. ASHS Press, Alexandria, VA. 1996.
[33] Scarth, R and Peter B.E. McVetty. Designer Oil Canola - A Review of New Food-Grade Brassica Oils with Focus on High Oleic, Low Linolenic Types. Proceedings of the 10th International Rapeseed Congress, Canberra, Australia. 1999. http://www.regional.org.au/au/gcirc/4/57.htm
[34] Warner, K. Soybean Oil Products: Composition, Quality and Stability. Adding Value to the Oil. 2002. http://www.pbi.nrc.gc.ca/en/bulletin/2002issue1/page6.htm

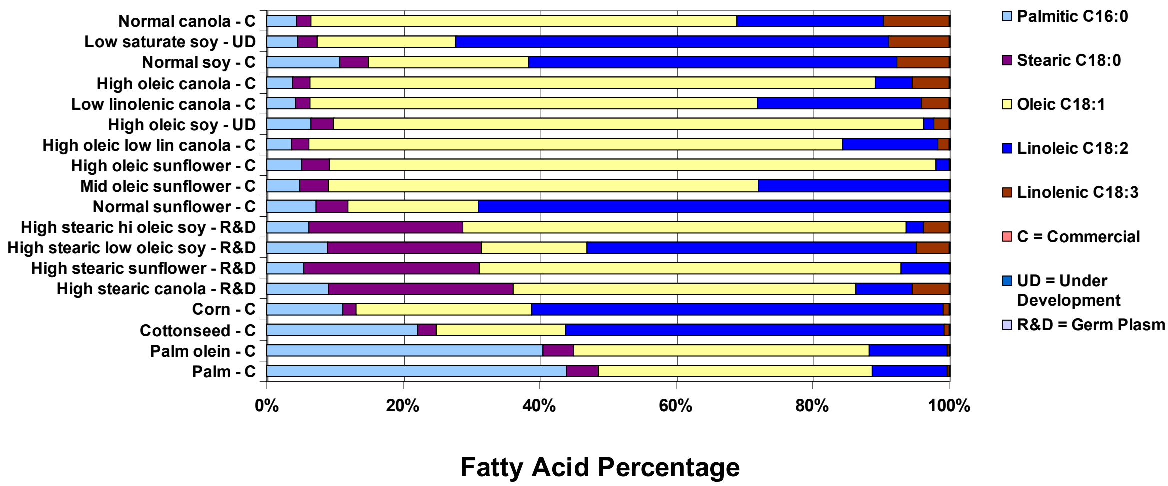

Figure 3. Fatty Acid Composition of Vegetable Oils

The low linolenic canola oil being marketed today in Canada benefits from mutation breeding initiated by Rakow over 30 years ago.[35] During the late 1980s, young biotechnology firms such as Allelix Crop Technologies, DNAP and Mycogen initiated private research to develop low linolenic canola varieties. These firms made significant technical progress but were not able to develop competitive varieties and seed sales quickly enough so the firms could continue as independent businesses. Some of the low linolenic canola germ plasm being commercialized today by Dow AgroSciences, Cargill Specialty Canola Oils and Dupont/Pioneer originates from these oilseed biotechnology firms. The Saskatchewan Wheat Pool has also supported breeding programs at the University of Manitoba to develop low linolenic canola. Some history of the development of low-linolenic canola genotypes is presented in a recent Cargill patent for a canola oil with reduced linolenic acid content.[36]

Soybeans with < 3% linolenic acid have been developed by Iowa State University, Monsanto and Pioneer and are beginning to enter commercial channels in the US.[37] Bunge's Nutrium™ low linolenic soybean oil comes from Pioneer Hi-Bred International, Inc. genetics and seedstock. Pioneer is a Dupont subsidiary. Cargill and Ag Processing Inc. are introducing a low linolenic soybean oil from soybean varieties bred by Monsanto's Asgrow division and marketed under the Vistive™ brand name. A soybean variety with < 1% linolenic acid developed by the ISU is being contracted for production by the Iowa Quality Agriculture Guild and the oil sold by Asoyia, LLC under the Asoyia™ brand name.

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[35] Rakow *et al.* "Opportunities and problems in modification of levels of rapeseed C18 unsaturated fatty acids. J. Am. Oil Chem. Soc, 50:400 – 403, 1973.
[36] DeBonte, L. R., Willie H. T. Loh, and Zhegong Fan. Canola oil, with reduced linolenic acid. US Patent 6,689,409 B2. 2004.
[37] Low-Linolenic Soybean Oil. http://www.zerotransoy.com/sol_lowlin_main.htm

3.1.2 Field Performance of Specialty Canola Varieties

Farm yields of canola increased by 24.5% during the ten years from 1990 to 2000.[38] The increase in farm yields reflects contributions of:

- Improved varieties with higher yields, particularly varieties with herbicide resistance and improved resistance to diseases.
- Improved agronomic practices with the adoption of herbicide resistant varieties.
- Better soil management, and fertilizer application practices.

Low linolenic canola varieties were grown on only a very small area during the 1990s. So the increase in farm yields of canola from 1990 to 2000 represent improvements in the production of canola varieties with normal fatty acid composition.

Farm yields are poised for a further increase now that canola hybrids are widely available for farmers. As seen in Figure 4, the yield of the best hybrid canola variety with a normal fatty acid profile was 128% of the check variety in the 2004 Prairie Canola Variety Trials.[39] The yield of the best low linolenic hybrid was 106.4 % of the check variety.

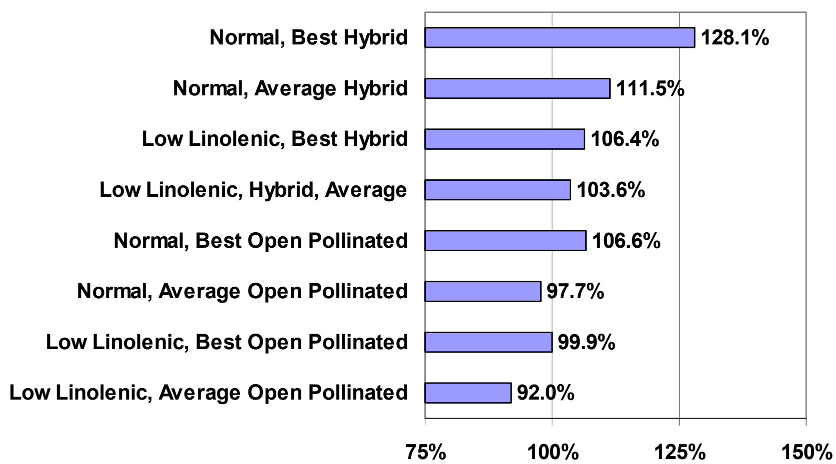

Figure 4. Yield Comparison of Canola Hybrids and Varieties in 2004

Observation: *The present low linolenic canola varieties are lower yielding than varieties with normal fatty acid composition. This is believed to be due to the relatively lower investment made over the past 15 years to breed low linolenic varieties compared to those with normal fatty acid composition. The yield difference between the normal and low linolenic canola genotypes represents a "lag" in the yield due to the lower investment in breeding and fewer generations of plant improvement. Research has not been done to determine if there is any "drag" or mpairment in the crop yield because of, for example, possible changes in the membrane lipid composition associated with the low linolenic trait.*

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[38] Serecon Management Consultants. (2002) "10-Year Review of Canada's Plant Breeders' Rights Act". Prepared for Canadian Food Inspection Agency.
[39] Saskatchewan Pool 2005 Seed Guide. www.swp.com

With the superior quality and expanding demand for low linolenic genotypes driven in part by the trans fat issue, the plant breeding industry is likely to increase its investment in breeding low linolenic genotypes adapted for Canada.

Driven by the trans fat issue, the plant breeding industry might consider investing to develop high stearic genotypes targeted for the solid fat markets.

3.1.3 Plant Breeding Investment in New Kinds of Crops

The annual private investment into breeding new canola varieties in Canada was reported to be ~$Cdn 22.5 million (1989 dollars) in 2000.[40] This is an increase from an average of ~$Cdn 7.1 million during 1988 – 1990. Investment in soybean breeding was ~$2.0 million (1989 dollars) in 2000.

At one time, the private sector was not engaged in breeding canola in Canada. This situation changed substantially during the 1970s with the expectation of plant breeders' rights and plant variety protection legislation. Private sector investment in oilseed breeding now exceeds that of the public sector, which has shifted its investment in oilseeds R&D to more basic science.

Observation: *Some canola breeders in Canada now have global mandates in which the Canadian market is just a part of the firm's global business in canola genetics.*

3.1.4 Identity Preservation of New Kinds of Oilseeds

Identity preservation of crops is difficult to achieve, particularly for those that cross pollinate. It is also difficult to maintain the separation of unique bulk oilseeds and oil products as they move through the storage, transportation and manufacturing systems. Experience has demonstrated the many challenges of identity preservation, at the farm level and also in the storage, handling, transportation and processing of bulk oilseeds and oils.[41]

In the absence of agreed tolerances in regulation or trading rules for mixtures of one specialty type of crop or product with another, identity containment may be needed to ensure the segregation of new materials in the food system. Absolute separation through identity containment is possible only with dedicated bulk handling facilities or where products are securely packaged.

Observation: *Any requirement for the Canadian food system to increase the number of discrete oilseed products produced on farms and segregated through the bulk handling, transportation and processing systems will experience many technical challenges and costs. The business risks and costs of identity preservation are large and should be appreciated. The costs of identity preservation will ultimately be borne by domestic consumers through the cost of the food they buy and by those selling products into exports markets, where the seller is more often than not a price taker.*

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[40] Serecon Management Consultants. 10-Year Review of Canada's Plant Breeders' Rights Act. For Canadian Food Inspection Agency, 2002.

[41] Private communications by industry players.

3.2 Fatty Acid Modification by Processing

3.2.1 Hydrogenation

Since its development in the 1920's, edible oil hydrogenation has remained relatively unchanged. The edible oil industry has relied heavily on nickel (Ni) catalysts to manufacture partially hydrogenated vegetable oils. These catalysts offer several advantages, including high activity, tailored linoleic and linolenic selectivities, low cost, and ease of separation from the processed oil. Unfortunately, these catalysts also isomerize the naturally occurring cis double bonds of unsaturated fatty acids to the trans configuration.

A simplified description of the hydrogenation process sheds light on the formation of trans isomers, and provides a logical starting point for exploring techniques to reduce trans isomers in a partially hydrogenated oil product.

The hydrogenation process consists of a series of reaction steps. When the fat molecule is adsorbed to the surface of the Ni catalyst, the double bond (the point where the molecule is unsaturated) bonds with the active site on the catalyst. The activated fat molecule can then react with a hydrogen molecule adsorbed on the catalyst surface, eliminating the unsaturation. If no hydrogen is available, the double bond can reform and leave the catalyst surface. The double bonds of a fat molecule have an almost equal chance of reforming either in the cis or the trans form. Thus half or more of the molecules that contact the catalyst where hydrogen is not available will form trans fats.

This leads to three strategies for reducing trans formation during hydrogenation to produce a partially hydrogenated oil with increased saturation:

- Increasing the hydrogen pressure so as to increase the amount of hydrogen on the catalyst surface.
- Using a less active catalyst with fewer active sites, so as to ensure that the catalyst surface always has enough absorbed hydrogen near the active sites. This can be achieved by producing catalysts with smaller surface area and less activation, or by pre-poisoning the catalyst and by blocking most of the active sites with a catalyst poison such as sulphur.
- Slowing the reaction down so as to allow more hydrogen movement to the catalyst surface before the fat molecule is released by the catalyst. This is most simply done by decreasing the temperature of the reaction.

A substantial increase in hydrogen pressure requires significant changes in equipment. Current reactors are operated at pressures less than 500 kPa, (5 atmosphere), while pressures of 5 MPa (50 atmosphere) may be required to provide sufficient hydrogen for significantly reducing trans formation. This alternative would require the replacement of the current hydrogenation reactors at a substantial cost.

The other two alternatives significantly decrease the reaction rate and result in the substantial decrease in the productivity of the hydrogenation reactor. Any increase in batch time from ~1 hour to 8 - 10 hours will be prohibitively expensive for the processor.

There has been an active search for catalysts to replace nickel. The work aimed at developing cis-selective catalysts (those that do not produce trans) was led by Frankel *et al* at the USDA.[42] They identified a number of catalysts, including chrome carbonyl complexes, that produce essentially no trans isomers. Unfortunately chrome carbonyl requires high pressure (3.5 Mpa or 500 psig), and as it is a homogeneous catalyst, it is difficult to separate from the oil. Reaction rates are slow and the catalyst is very toxic. Still, the work identified a possible mechanism for producing partially hydrogenated oil with very little trans fat.

Copper chromite has been commercially tested as a less reactive, cis selective catalyst. It will result in decreased trans production, but at a cost of poor linoleic selectivity and slow reaction rate.

A number of platinum group metals were shown to be very active, even at very low concentrations. Although they produced high levels of trans, because of their high activity it was possible to run the reaction at very low temperatures, and still obtain a reasonable throughput with reduced trans. Homogeneous catalysts were more suitable for cis selectivity. Work on immobilizing these catalysts is in the early research stage.

> **Observation:** *It is unlikely that zero trans or trans levels down to 1% will be achievable with any of the known modifications to the hydrogenation process. However, there are opportunities to reduce trans isomer production during hydrogenation by an order of magnitude, to perhaps 5% - 10% trans fatty acids in certain basestocks.*

3.2.2 Blending of Basestocks

Blending fats with different degrees of saturation can be used to alter the melting characteristics and increase the range of plasticity of the resulting product.[43,44,45] Blending can also be used to control crystalline structure or polymorphism in fats. For example, to maintain the desirable β'-crystal in margarines and cake shortenings, a β'-crystal tending fat like palm oil or hydrogenated palm oil can be incorporated in a blend.

> **Observation:** *Zero or low trans plastic fats can be produced by blending, but with some of the blending fats having high levels of saturates. It is difficult to obtain blended fats with the melting characteristics of hydrogenated fats, because blending combines low melting liquid oils with high melting saturated fats, with few of the TAGs having melting points characteristic of TFA near the body temperature. The liquid oils in the blend can contribute an oily taste, while the high melting saturated fats can be grainy.*

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42 Frankel, E.N., Selke, E and Glass, CA JAOCS 46:256, 1968.

43 Nor Aini, I. "Trans-free vanaspati containing ternary blends of palm oil-palm stearin-palm olein and palm oil-palm stearin-palm kernel olein." J. Am. Oil Chem. Soc. 76: 643, 1999.

44 Pal, P. K., D. K. Bhattacharyya, et al. "Modifications of butter stearin by blending and interesterification for better utilization in edible fat products." J. Am. Oil Chem. Soc. 78: 31, 2001.

45 Danthine, S. D., C. "Blending of hydrogenation low-erucic acid rapeseed oil, low-erucic acid rapeseed oil, and hydrogenated palm oil or palm oil in the preparation of shortenings,." J. Am. Oil Chem. Soc. 80: 1069, 2003.

3.2.3 Fractionation

Fractionation involves selectively crystallizing TAG species with higher saturates and separating them from the liquid oil.[46,47] This technique is used during the "winterization" of oils to remove high melting TAGs which would otherwise crystallize during storage. To prevent retail salad oils from becoming cloudy when refrigerated, cottonseed, sunflower and lightly hydrogenated soybean oils are winterized - the oil is cooled to ~ -10°C and the precipitated solid fats and waxes removed by filtration. A distinguishing feature of canola oil is that it does not need to be winterized to remain clear at refrigerator temperatures.

Fractionation of palm oil results in the unsaturated palm olein and saturated solid fractions having desirable melting properties for use in confectionary applications. Palm olein has high oxidative stabilities suitable for frying. The higher melting fractions are used as cocoa butter substitutes or basestocks in margarines and shortenings.[48]

> ***Observation:*** *Fractionation is widely used to improve the functionality of fats and results in products with differing melting points, solid fat contents, and hardness. Plastic fats with zero trans fatty acids but having high levels of saturates can be prepared by fractionating palm, mango kernel and mahua fats and recombining the fractions in different proportions. The fractionating of high stearic canola and soybean oils to recover saturated fat fractions with useful properties for manufacturing margarine and shortening has been demonstrated.*

3.2.4 Interesterification

Interesterification has a proven track record in terms of its ability to tailor the consistency of fats and oils. When blends of palm hardstocks and vegetable oils are chemically randomized, products with a range of consistencies suitable for margarine, shortening, and confectionary applications are produced.[49] Interesterification generally results in a decrease in the blends' melting range by eliminating the highest melting TAGs present in the hardstock.[50,51] Interesterification may also change the polymorphic behaviour of blends, creating a β'-crystal.[52] This type of crystal provides a smooth consistency and desirable functionality in applications such as whipped toppings and cake batters.

The technique involves exchanging fatty acids between the TAGs in a mixture. It is a catalytic reaction, involving the hydrolytic release of some fatty acids, and their random reattachment to the glyceride. The reaction is catalyzed chemically or by enzymes:

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46 Hamm, W. "Trends in edible oil fractionation." Trends Food Sci. Technol. 6: 121, 1995.
47 Illingworth, D. Fractionation of Fats. Physical Properties of Lipids. A. G. Marangoni and S. S. Narine. New York, Marcel Dekker.: 411, 2002.
48 Jeyarani, T. and S. Yella Reddy. "Preparation of plastic fats with zero trans FA from palm oil." J. Am. Oil Chem. Soc. 80: 1107, 2003.
49 Karabulut, I., S. Turan, et al. "Effects of chemical interesterification on solid fat content and slip melting point of fa/oil blends." Eur. Food Res. Technol. 218: 224-229, 2004.
50 Rousseau, D. and A. G. Marangoni. "Tailoring the textural attributes of butter fat/canola oil blends via *Rhizopus arrhizus* lipase-catalyzed interesterification 2. Modifications of physical properties." J. Agric. Food Chem 46: 2375-2381, 1998.
51 Noor Lida, H. M. D. *et al.* "TAG composition and solid fat content of palm oil, sunflower oil, and palm kernel olein blends before and after chemical interesterification." J. Am. Oil Chem. Soc. 79: 1137, 2002.
52 Norizzah, A. R., C. L. Cong, et al. "Effects of chemical interesterification on physicochemical properties of palm stearin and palm kernel olein blends." Food Chem. 86: 229-235, 2003.

- Chemical interesterification (CIE) lacks specificity and several TAG products which may not be desired are produced in the blend. It is possible to direct interesterification reaction somewhat, by removing desired, high melting point fractions as the reaction proceeds. Chemical interesterification is relatively inexpensive and is in industrial practice, particularly in Europe, to produce plastic saturated fats with zero or low trans fat levels .[53]

- Enzymatic interesterification (EIE) offers more control over the reaction products that form. Enzymes are highly specific, and may be selected to cleave specific ester bonds in terms of their position on the molecule. EIE can be carried out at lower temperatures than CIE, so less thermal degradation occurs. Unlike chemically interesterified oils, enzymatically interesterified oils do not require washing and bleaching.

Low or zero trans plastic or solid interesterified fats produced by either chemical or enzyme interesterification will contain the saturated fats of the original feedstocks.

There are many reports of the EIE of fats and oils to produce products with unique physical properties. The specificity possible with EIE is a huge advantage of this technology. Another advantage is that it proceeds at lower temperatures than CIE, so less thermal degradation occurs. Also, while chemically interesterified oils require washing and bleaching, enzymatically interesterified oils do not. This represents a significant cost savings for EIE.

The barrier to the wide-spread adoption of EIE initially was the high cost of the lipase enzyme. In 1994, the Danish enzyme producer Novozymes began to market Lipolase™, a recombinant lipase obtained by cloning the *Thermomyces lanuginosus* lipase gene into the *Aspergillus orzyae* genome.[54, 55] The lipase is produced cost efficiently by submerged fermentation.

Immobilization of Lipolase has further reduced cost by allowing for enzyme reuse and increasing the pH and temperature stability of the lipase. De Smet in collaboration with Novozymes has developed a continuous fixed-bed Lipolase interesterification process called Interzym.[56] The process is reported to have lower capital and operating costs than hydrogenation and chemical interesterification (Figure 5).[57]

ADM has commissioned the first commercial enzyme interesterification facility in North America at Quincy, Illinois. Its NovaLipid™ product line includes naturally stable oils, fully hydrogenated soybean fats, tropical oils, blended oils, and enzyme interesterified shortenings

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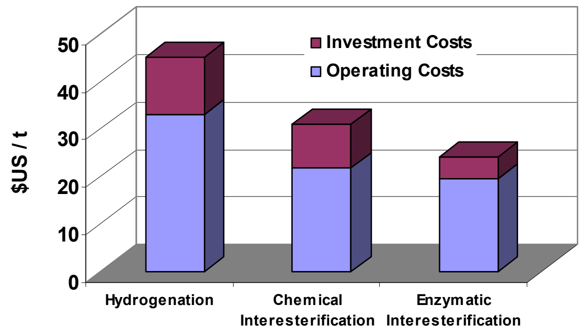
53 Willis, W. M. and A. G. Marangoni. "Assessment of lipase- and chemically catalyzed lipid modification strategies for the production of structured lipids." J. Am. Oil Chem. Soc. 76(4): 443-350, 1999.
54 Ashok Pandey, Sailas Benjamin, Carlos R. Soccol, Poonam Nigam‡, Nadia Krieger and Vanete T. Soccol. The realm of microbial lipases in biotechnology. Biotechnol. Appl. Biochem. 29, 119–131, 1999. http://www.babonline.org/bab/029/0119/bab0290119.htm#REF10
55 U. S. Food and Drug Administration, Center for Food Safety & Applied Nutrition, Office of Premarket Approval. Agency Response Letter. GRAS Notice No. GRN 000043. September 22, 2000.
56 Desmet Bellastra. Fat Modification. http://www.desmetgroup.com/desmet04/fatmodificat.html
57 David Cowan and Tommy Lykke Husum. Enzymatic Interesterification: Process Advantages and Product Benefits., Novozymes A/S, Oils & Fats Business Development Team, Denmark; and Novozymes North America, Inc., Oils & Fats Business Development Team, USA. Inform 15(3) 150 – 151, 2004. Also, http://palmoilis.mpob.gov.my/publications/pod39-p7.pdf

and margarines. Enzymatically interesterified soybean fats containing greater than 20% stearate content will be labeled "high stearate" or "stearic rich" interesterified soybean oil".[58]



Source: Enzymatic Interesterification: Process Advantages and Product Benefits. www.novozymes.com

Figure 5. Comparison of Costs for Fatty Acid Modification

3.3 Use of Saturated Fats

The saturated fats needed to make margarines and shortenings in Canada will originate from three sources:

- Domestic: Fully hydrogenated C18:0 canola and soybean fats.
- Domestic: Animal fats – tallow and lard.
- Imported: Tropical oils – palm and coconut.

In the North America, animal fats were initially the primary source of fat in the diet. The original margarine formulations relied on fractionated tallow as the fat source. These were replaced by hydrogenated whale oil - in products that would be considered awful today. The production and use of vegetable oils in Canada increased rapidly during the Second World War due to shortages of animal fats and protein. After the war, the increased demand and stable supply of animal fats made them more expensive than vegetable oils and oil products, and vegetable oils made a steady inroad into the markets of dairy fats and animal fats.

Coconut oil, pressed from fully mature coconuts (copra), have been traditionally available from tropical plantations in Africa, Asia and the Caribbean. The oil has been in demand due to its special flavour, and stability. However, the price of coconut oil has fluctuated wildly due to competition from other oils and production problems due to insects.

Oil palm is an excellent source of two oils: palm oil and palm kernel oil. Palm oil is high in saturated palmitic acid (16:0), while palm kernel oil is high in lauric acid and also contains both monounsaturates and the saturated 14:0. When the market for natural rubber collapsed, due to the development of petroleum-based alternatives, Malaysia and Indonesia

[58] Archer Daniels Midland Company. ADM To Expand NovaLipid Line of Zero/Low Trans-Fat Oils and Margarines http://www.admworld.com/presspdf/NovaLipid_expansion_announcement.pdf

converted their rubber plantations to palm oil production. As these plantations came on stream in the mid 1970's, the availability of palm oil skyrocketed. Other countries in Africa, Asia and South America followed with production of their own.

The supply of cheap palm oil was welcomed by food processors who:

- Developed simple cost-effective physical refining techniques for palm oil, and
- Started to incorporate palm oil in many food products.

By 1991, palm oil represented 33% of world trade in oils and fats and palm oil was the dominant food oil source for more than 90 countries.[59] The oil initially delivered to North America was often of low quality due to poor processing and shipping techniques. However, this changed as serious technology development efforts began, driven primarily by palm oil producers in Malaysia.

In an effort to protect their markets, soybean producers campaigned against palm oil, and persuaded the US Congress to mandate labeling "tropical oils" in consumer products. While this slowed the expansion of palm oil usage, tropical oils remained an integral part of the North American product mix and with the trans fat issue is seeing increased use.

3.4 Use of Antioxidants

A number of additives may be included in food products, that will improve the stability of the fat or contribute to the desired functionality provided now by trans fats.

Antioxidants are compounds that delay or inhibit the oxidation of fats and oils and are used to improve shelf life of edible oils. Antioxidants do not eliminate oxidation altogether. Instead, they extend the time before which an oil begins to turn rancid.

There are several phenolic antioxidants that are safe and effective at low addition levels. These include BHA (butylated hydroxanisole) and BHT (butylated hydroxytoluene), and PG (propyl gallate). They often interact in synergy with each other, and other food additives such as citric acid. While these compounds are highly effective, public aversion to chemical additives discourages their use. Curiously, natural products (e.g. rosemary extract) which contains the same or similar phenolic compounds, together with some more toxic ones, are gladly accepted.

Tocopherols (vitamin E) are natural antioxidants present in many edible oils. The deodorization process can remove some or all of the tocopherol through vacuum steam distillation, and this is the source of most vitamin E preparations. With the need to increase oil stability, manufacturers might try to retain more tocopherols in the oil, and add back tocopherols from other natural or synthetic sources.

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[59] Augustine S. H. Ong, Malaysian Palm Oil Promotion Council. Nutritional aspects of palm oil: an introductory review. Asia Pacific J Clin Nutr. 3, 201-206. 1994. http://elecpress.monash.edu.au/APJCN/Vol3/Num4/34p201.htm

3.5 Fat Replacers

A strategy for reducing or eliminating trans fatty acids in the diet is to decrease the overall fat content in foods.[60] Fat replacement solutions will become very important if it is determined that the levels of saturated fats should not increase as trans fats are reduced.

With few exceptions, fat replacement will require product reformulation in order to achieve the desired properties. When fat is removed from most products, bulking is required. In addition, other functionalities such as melting or lubricity are compromised.

Fat replacers are ingredients which mimic the functionality and sensory properties of fat, but contribute fewer calories. Fat replacers can be based on lipid, protein, or carbohydrates.

Olestra and Salatrim are examples of lipid-based fat replacers. Protein- and carbohydrate-based fat replacers are hydrophilic ingredients which can mimic some of the behaviour of fats. These compounds are specifically referred to as fat mimetics because they only partially replicate the role of fat in a food product.

Selection of a suitable fat replacer requires a solid understanding of the food system in question and careful weighing of the advantages and disadvantages of each product. In many cases, a blend of various ingredients offers the best solution to fat reduction. Some of the most common ingredients that might be used as fat replacers are discussed in this section. We note however that several ingredients that might be useful in reducing trans fats in foods are not approved for use in Canada.

3.5.1 Lipid-Based Fat Replacers

Lipid-based fat replacers have the advantage that they are lipid soluble and therefore better replicate the functionality of traditional fats than carbohydrate- and protein-based ingredients. They also have higher heat stabilities and can be used in cooking and frying.

Lipid-based alternatives also help to maintain the typical flavour profile in a food. Hydrophobic flavours are carried by the fats and oils present in foods and slowly released during chewing and swallowing. Therefore fat is important not only from a texture standpoint, but also in terms of flavour by prolonging the release of flavour compounds. When fat is removed from foods, the flavour release tends to be much more rapid and short-lived.

3.5.1.1 Emulsifiers

Emulsifiers are compounds that are attracted to both oil and water. Their primary functions in foods are the formation of stable emulsions that combine water and oil in products such as salad dressings, fat spreads, and ice cream. They are also used as dough conditioning agents, to enhance aeration in batters, and to prevent bloom in chocolate. The most commonly used food emulsifiers are mono- and di-glycerides i.e. TAGs where one or two of the fatty acids are replaced by hydrogen, providing a hydrophyllic position on the molecule.

[60] Guelph Food Technology Centre. Fat Replacers & Extenders. *Functional Foods & Nutraceuticals, June 2004*. http://www.gftc.ca/newslett/2004-12/fat-replacers-extenders.cfm

Emulsifiers can be used specifically to alter the functionality of fats. For example, in cake batters, emulsifiers allow for better incorporation of air so that smaller air bubbles are produced. This leads to a finer grain and desirable crumb in cakes and cookies. In some cases, emulsifiers may allow the replacement of a shortening with liquid oil, although this is not suitable for applications where a crystalline fat is required.[61] Plastic shortenings used in the baking industry commonly contain 5 - 10% mono- and di-glycerides. Emulsifiers also alter the crystalline structure of fats. They can be used to prevent cloudiness in refrigerated salad oils, to achieve desirable plasticity in margarines, and to manipulate the polymorphic behavior of fats. This is important in achieving a smooth fat spread.

Several emulsifiers have the ability to enhance reduced-fat products. They typically do this by extending the functionality of the fat which is present. In a sense, they can help to make a little fat go a longer way. Partial acylglycerols, lecithin, sodium stearoyl lactylates, diacyltartaric esters of mono- and diacylglycerols are examples of lipid-based emulsifiers with potential in reduced fat foods.

3.5.1.2 Diacylglycerols

Enova is a diacylglycerol (DAG) oil sold in North America by Archer Daniels Midland Company (ADM) and Andrew Jergens Company (a subsidiary of Kao Corporation, Tokyo). In DAGs, only 2 fatty acid molecules are esterified to the glycerol backbone (TAGs contain 3 fatty acids). Although these fats contribute 9 kcal/g as do typical TAG-based fats, there is evidence that DAG oils lead to weight reduction and decreased body fat in humans. DAG oils have similar functionality to conventional fats in various applications including cooking and frying, baking, salad dressings, and dairy-based products. Efforts to incorporate DAG oils into various food products are underway.[62] Vegetable diacylglycerol oil was recently reviewed as a novel food by Health Canada.[63]

3.5.1.3 Medium Chain Length Triglycerides

Medium chain triglycerides (MCTs) contain fatty acids generally between 6 and 12 carbons in length. Nutritionally, they are relevant because they contribute only 8.3 kcal/g of energy as opposed to the 9 kcal/g for longer chain fatty acids. As a result, the incorporation of MCTs in foods can result in a modest reduction in calories. MCTs tend to be liquid at room temperature and relatively stable to oxidation. Because they are TAGs, they behave similarly to other oils and fats in food. They also have the potential to raise serum cholesterol levels.

3.5.1.4 Salatrim

Long chain saturated fatty acids have limited absorptive capacity in the body, partly because of their relatively high melting temperatures. As a result, they contribute fewer calories per gram than some of the shorter and saturated fatty acids. A compound called salatrim, which

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[61] Kuntz, L.A., Where is fat reduction going? *Food Prod. Des.,* March, 1996. http://www.foodproductdesign.com/archive/1996/0396CS.html
[62] Boice, B., Egbert, R., Sikorski, D.M., Stuchell, Y.M., and Widlak, N. Foods and drinks containing diacylglycerol. US Patent 2004/0009284 A1, 2004.
[63] Health Canada. Novel Food Decisions. September 10, 2004. http://www.hc-sc.gc.ca/food-aliment/mh-dm/ofb-bba/nfi-ani/e_nf_dec.html

is sold in the US and EU by Danisco under the tradename Benefat™, takes advantage of this fact. Salatrim is not approved for food use in Canada.

Salatrim is an acronym for "short and long chain triacylglycerol molecules". This class of TAGs contains both short and long chain fatty acids. Typically, acetic, proprionic or butyl acids (C2-C4) are interesterified with one much-longer-chain fatty acid such as palmitic, stearic, arachidic or behenic, acid (C16-22). Because of the limited absorption of the long chain saturates and the lower heats of combustion for the short chain fatty acids, these compounds can contribute as little as 5 kcal/g. There are a variety of Salatrim products available for confectionary, baking, and spread applications with further ones in development for frozen and dairy applications.

3.5.1.5 Olestra

Olestra represents a non-traditional synthesized lipid-soluble ingredient. The compound is a sucrose polyester in which fatty acids are esterified to a sucrose backbone. Depending on the fatty acids present, various physical and chemical properties are achieved.

The chemistry of Olestra is such that it is not hydrolyzed by digestive enzymes. Therefore, it contributes no calories. Olestra is claimed to have similarities to traditional fat in terms of mouthfeel, high heat stability, shelf life, and flavour-carrying ability. The biggest drawback to Olestra is that, because it remains undigested, it can cause gastrointestinal upset and may have a laxative effect. Olestra may also decrease the absorption of fat-soluble nutrients. Olestra is not approved for food use in Canada.

3.5.2 Carbohydrate-Based Fat Replacers

Carbohydrates and proteins can be used to mimic the properties of fats in some instances. This primarily occurs through their ability to interact with water. These molecules bind water and contribute bulk, mouthfeel, and lubricity which can be similar to fat. The requirement for water in these systems, however, can lead to decreased microbial stability and shelf life, changing the freezing-point depression and reducing the emulsion stability.

Carbohydrate-based fat replacers are typically not viable options for low-moisture foods. Starches, maltodextrin, polydextrose, inulin, hydrocolloid gums and fiber are examples of carbohydrate fat mimetics. This represents a very large group of compounds which help to thicken foods and provide structure. Some of the carbohydrate molecules including cellulose are not digestible and therefore contribute negligible calories. The digestible carbohydrates contribute up to 4 kcal/g depending on their level of hydration and specific chemistry. Polyols, for example, are not fully absorbed and metabolized so they contribute fewer calories, but may also have a laxative effect.

Because starches are able to bind water, they are very useful as thickening or gelling agents. They are commonly used to partially replace fat functionality in high-moisture bakery products, meat products, and dips. In addition to offering a range of functionality, modified starches are typically economical fat replacers. The choice of carbohydrate will vary depending on temperature, pH, and desired texture, among other variables. For example, low dextrose equivalent maltodextrins are suitable for either increasing viscosity or gelation. Ingredients have been prepared to mimic other qualities of fats in foods. For example, the mouthfeel and structure of fat crystals can be achieved using microparticulated intact starch granules in foods. In addition, combinations of ingredients is often most beneficial to achieve a desired outcome.

Resistant starches are a class of starches that are not digested in the small intestine, although they are fermented in the large intestine. These include starches which are physically inaccessible, granular and ungelatinzed, high in amylase, retrograded after gelatinization, and chemically modified. Resistant starches have received a fair bit of attention lately because of the interest in low-carb diets. Compared with other carbohydrate-based ingredients, these molecules have low-water holding capacity. They can be used in applications such as breakfast cereals, pasta, extruded snacks, baked goods, and other low-moisture foods. Different types of resistant starches exist.

Polydextrose is a polymer of randomly joined glucose molecules. While the low-molecular weight versions are used as sugar replacers, the higher-molecular weight polydextroses mimic the smooth mouthfeel of fat. Polydextrose is primarily used as a bulking agent in reduced-fat foods. Because up to 90% of polydextrose is fiber, it supplies only 1 kcal/g.

Fiber, in general, from various plant sources can be used as partial fat replacers. These compounds have the advantage that most supply 0 kcal/g and offer further nutritional benefits such as aiding gastric motility. Like starches, fibers can contribute texture, form gels, and control water, depending on their specific composition. Fruit purees or puree powders based on plums, apples or pears are rich in fiber and can aid in the reduction of fat in some applications, particularly baked goods. Ingredients with fat-replacing potential can also be found in other plant/vegetable matter. For example, Z-trim is a new ingredient being sold in the US that is made from processed rice, pea, soybean, or oat hulls or from corn or wheat bran. The materials are processed into tiny non-metabolizable fragments which are purified and milled into a dry powder which absorbs water and swells into a smooth fat replacer.

Inulin is extracted from the chicory root and, although it is fibrous, it lacks the typically gritty taste of many fibers. Inulin refers to a group of products which are mixtures of fructose oligomers and polymers with a terminal glucose group and linked by beta (2-1) bonds. Inulins range from 1.0 - 1.5 kcal/g and have various functionalities and nutritional benefits. For example, inulin can increase calcium absorption and promote the growth of beneficial bifidobacteria in the gut. In terms of fat replacement, some inulins can be mixed with water and sheared to produce a creamy gel texture with applications in reduced fat spreads and creamy-cheese products. Although some inulins are slightly sweet, others have a neutral flavour and all offer a clean taste. Fat reduction has been achieved in spread, dressings, baked goods, dairy products and frozen desserts.

Hydrocolloid gums may also be useful when reformulating foods for lower fat. Gums such as, xanthan, locust bean gum, guar, pectin, alginates, and carrageenans have high water-holding capacity. Because of this, they help stabilized emulsions, reduce freeze/thaw susceptibility, prevent syneresis, and provide texture and mouthfeel in foods. Cellulose, microcrystalline cellulose (a product derived by treating cellulose with acid), and other cellulose derivatives can be used to create fat-like structures. For example, when microcrystalline cellulose is dispersed in water and stirred, the chains form a soft and creamy gel with fat-like texture.

Again, the application will dictate which one or combination of hydrocolloids is most appropriate.

3.5.3 Protein-Based Fat Replacers

Proteins for fat replacer ingredients can be sourced from egg, whey, gelatin, and wheat gluten. Proteins are amphiphilic and will therefore act as emulsifiers. For fat reduction, proteins are used after being processed into microparticulated form (roughly 0.5 to 2 μm in diameter). This design makes protein-based fat replacers superior to their carbohydrate-based counterparts.

Ingredients like Simplesse made of whey protein act like tiny ball bearings and provide a smooth and slippery mouthfeel in products with relatively high moisture contents such as salad dressings, sauces and frozen dairy desserts. They are also functional in baked goods, provided the proteins used are heat stable. Protein-based fat mimetics are not suitable for frying because of their heat susceptibility. In some cases, protein fat replacers are tailored for a specific application by carefully controlling the denaturation.

The microparticulated ingredients provide roughly 1.3 kcal/g. Whey protein isolates contain 4 kcal/g and have excellent fat-like functionality in some applications, particularly when further processed into microparticles. They are especially useful in frozen dairy desserts because it prevents shrinkage and ice crystal formation. Soy protein isolates, while not specifically fat replacers in terms of functionality, can be added to products to simply reduce the concentration of fat present. Protein-based fat replacers tend to mask flavours in foods. In addition, there may be concerns about allergenicity depending on the source. Simplesse received US FDA approval in 1990 and Health Canada considers it a natural food ingredient.

4. Initiatives to Reduce Trans Fats

4.1 Investment

Requirements to re-formulate to zero or low trans products in Canada call for new ingredients, new processes and new products. It should be appreciated that some alternatives to trans fats may result in altered or degraded physical and sensory properties of some foods. The nutritional benefits of the replacement products should also be validated as many will increase the levels of saturated fat and some may create nutritional deficiencies that will need to be addressed. Solutions for zero or low trans fats in Canada will require:

- Investment in research, food engineering and product development, or
- Import of research, replacement technologies and products from elsewhere.

For small volume and low margin products where the investment cannot be justified, the manufacturer may find it necessary to withdraw the product from the Canadian market – depending on consumer expectations and regulatory approaches to trans fats.

The Canadian industry has been investing for some time in many different areas of plant and food science, food process engineering, product development and marketing to reduce or eliminate trans fats from the food supply. These include:

- Improved varieties with new output traits.
- New crop production schemes and value chains.
- New value-adding or cost-reducing manufacturing processes.
- New formulations and product targets.
- New approaches to distribution, marketing and communications.

4.2 Public Awareness and Education about Oils and Fats

Trans fats are the controversy now, and a communications and public education challenge for the industry and governments.

The public appears to be increasingly aware of trans fats, but perhaps not aware that it is not possible to make solid and semi-solid fat products used in some baked goods without the use of either trans fats or saturated fats. There is likely even less known by the public about the relative nutritional demerits of palmitic and stearic fatty acids and the nutritional benefits of linolenic acid.

The food industry may be faced with needing to convince a skeptical public that saturated fats are acceptable, at least in some foods, where alternatives are not available and economic.

4.3 Health Benefits of Low / Zero Trans Products

To re-formulate hardstocks to zero or low trans fat products, the oil refiners are expected to increase their use of:

- Tropical oils – high in palmitic acid and moderate in stearic acid.
- Fully hydrogenated oleic oils such as soy or canola oil – high in stearic acid, and
- Animal fats – high in stearic and palmitic.

With long standing consumer concerns about animal fats because of cholesterol, and now BSE, it seems certain the food industry will turn to cheap imported tropical oils with high palmitic acid for their saturated feedstock to manufacture margarines and shortenings.

The industry may rely on research indicating that not all saturated fatty acids are equally harmful. Some research suggests that stearic acid (18:0) is less hypercholesterolemic than lauric, myristic, and palmitic acids (12:0, 14:0, and 16:0, respectively). This difference is partly attributed to the decreased absorption of stearic acid. Zero or low trans plastic fats are possible using high stearic fats produced from fractionated hardstock, fully hydrogenated oils or from high stearic canola or soybean oils that have yet to be commercialized.

We note that the scientific information of the relative degrees of harmfulness of trans fats and the various saturated fatty acids is not unequivocal. A recent British study, which is the first to claim detailed understanding of the mechanism of how saturated fats and trans fats elevate LDL and lower HDL concluded that the same metabolic pathway is responsible for the action of trans and saturates, and therefore their effects must be the same or very similar.[64]

> ***Observation:*** *As many of the techniques being adopted by the industry to replace trans fats rely on the increased use of palmitic and stearic saturated fats, further research as to health implications and merits of these new palmitic and stearic saturated fat formulations as replacements for trans fatty acid formulations seems warranted.*
>
> *While trans fats are a hot topic today, most trans mitigation strategies being implemented do not reduce caloric intake. It has been suggested that obesity mitigation could be a bigger issue for everyone to deal with.*[65]

4.4 Categories of Oils and Fat Use and Trans Fat Change

The trans fat challenge impacts Canada's food industry in four of the five main categories of oils and fats use (Table 2):

- Salad oils.
- Margarines and Spreads.
- Frying oil for food service and quick service restaurants.
- Industrial Frying and Processing.
- Baking shortenings.

The timeframe to make significant changes in the trans fat contents in these five areas of oils and fats use is summarized in Table 2.

4.5 New Processing Techniques

There is no drop-in solution suitable for all applications. Foods are complex systems and changing one ingredient or one processing operation can have significant implications on the product quality.

The challenges associated with reformulating food products to decrease or eliminate trans fatty acids depend on the application. They are especially significant in products which require solid fat in some way.[66,67]

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[64] reference
[65] Dave Forster, Bunge Canada. Frying Oils: Consumer and Suppliers' Perspective. Proceedings: Seminar Fats and Oils. ICSTA Section du Québec. Montreal, Québec. October 14 – 15, 2004.
[66] Thomas Tiffany, Archer Daniels Midland Company. An Overview of Viable Alternatives to Reduce Trans Fatty Acids. Proceedings: Seminar Fats and Oils. ICSTA Section du Québec. Montreal, Québec. October 14 – 15, 2004.
[67] Bob Johnson, Bunge Oils, USA. Functional Properties of Fats in Food Applications. Proceedings: Seminar Fats and Oils. ICSTA Section du Québec. Montreal, Québec. October 14 – 15, 2004.

Table 2. Timeframe to Change Oils Used in Foods to Low Trans Fats

Food Use	Comment	Timeframe for Canada: Now	1 – 3 Years	4 – 8 Years	9 – 15 Years
Salad oil, cooking oil and salad dressings	Retail bottled oil and salad dressings. Products visible to the consumer. Oils naturally zero in trans fats.	X			
	Deodorization produces small amounts of trans, but likely less in canola than soybean.	X			
	Normal canola oil used, not brush hydrogenated. Low linolenic canola no advantage in these retail products.				
	Soybean oil, if brush hydrogenated, contains small amounts of trans fats.	X			
	Low linolenic soybean oil will eliminate need to brush hydrogenate to increase oil stability.	X	X		
Margarines and Spreads	Retail products require varying amounts of hardened basestocks which are high in trans fats. Products are visible to the consumer.	X			
	Unilever's Becel margarine has been marketed for 20 years as a product high in polyunsaturates. The tub margarine is a low trans fat formulation. [68]	X			
	Many soft margarines on the shelf based on palm and stearine fractions. Product improvements in pipeline.	X	X		
	Low trans hard margarines possible today if processors ignore functionality and cost. New products in pipeline, but containing palm and stearine fractions.		X		
Frying oil – food service and QSR	Heavy duty frying requiring stable fats. Fat absorbed into the product is not visible to the consumer.	X			
	New low linolenic /high oleic canola and sunflower oils are being aggressively advertised and adopted as low trans alternatives, but with some loss of functionality and sensory properties in some applications.	X			
	High stability hydrogenated canola and soybean oils used, but with trans fats. Low trans fats in pipeline.		X		
	Low linolenic soybean oil being commercialized in US.	US	US	Cda	
	Dupont high oleic soybean oil trait approved in Canada.	X	X		
Industrial frying and food processing	Retail products such as potato chips, tortilla chips, frozen french fries, etc. are made using partially hydrogenated snack frying oils. Fat not visible to the consumer.	X			
	Challenges remain for low trans replacements in doughnut frying and spray oils.	X	X		
	Low linolenic /high oleic canola and sunflower oils are being adopted as low trans snack frying alternatives, with acceptable functionality and sensory properties.	X			
	Low linolenic soybean oil being commercialized in US.	US	US	Cda	
	Dupont high oleic soybean oil trait approved in Canada.	X			
Baking shortenings	Industrial and retail applications. Wide range of product specific functionalities required. Partially hydrogenated vegetable oils and animal fats have been used. Both contain trans fats and saturated fatty acids.	X			
	Fractionated and interesterified high palmitic and stearic oils and fats are prospective replacements for the trans fats produced by hydrogenation.	X	X		
	Formulation challenges for low trans replacements for All Purpose Shortening, Emulsified Shortenings and Pastry Roll-Ins where specific functionalities are required.	X	X		

[68] Uniliver. Walking Towards a Healthy Heart. http://www.becelheartday.ca/product_information.asp

The melting properties of zero or low trans fats is a challenge. Obtaining the appropriate melting characteristics to produce acceptable zero or low trans substitutes for partially hydrogenated vegetable oils is an obstacle in specific food applications, such as doughnuts, croissants, danishes and other pastries. The quality of these products depends heavily on the functionality of the fat and specifically a certain degree of crystallinity. The solid fat content (SFC) or solid fat index (SFI) depends on the range of melting temperatures of the triacylglycerols present. *Cis* unsaturated fatty acids are liquid at room temperature and cannot contribute solids or hardness. In contrast, trans unsaturated fatty acids and saturated fatty acids have higher melting temperatures. Therefore, fats which contain higher proportions of these fatty acids are partially crystalline at room temperature, i.e. they are "plastic" fats.

To achieve plastic fats with the desired crystallinity, processors can use a variety or combination of the techniques i.e. sourcing alternate basestocks, blending, fractionation, interesterification and hydrogenation (Table 3).

Table 3. Timeframe to Implement Processing Changes

Process	Comment	Timeframe for Canada			
		Now	1 – 3 Years	4 – 8 Years	9 – 15 Years
Hydrogenation	Mature technology. Order of magnitude reduction in trans fat possible. Zero trans not possible with partial hydrogenation.	X			
Blending	Mature technology. Rely in imported tropical oils & fats and hydrogenated canola / soybean stearine.	X			
Fractionation	Mature technology. Rely in imported tropical oils & fats and hydrogenated canola / soybean stearine.		X	X	
Chemical Interesterification	Mature technology. Used in Europe to greater extent than in North America. Some capacity in Canada.	X	X		
Enzymatic Interesterification	Emerging technology in Europe and North America. Significant reduction in capital and operating costs in past 5 years. Technology of choice to reduce or eliminate trans fat. Very many product potentials beyond trans fat mitigation.		X	X	X

Enzymatic interesterification appears to be the most versatile and least cost process available to oil refiners to reduce or eliminate trans fats from the food supply. The process can be used to:

- Replace hydrogenated fats with zero trans alternatives.
- Improve the spreadability and baking properties of lard
- Manufacture inexpensive confectionary fats.
- Produce structured lipids with specific health benefits.

4.6 New Oilseed Genetics

The challenges facing Canadian plant breeders, crop developers, and oil refiners are to:

- Determine the most desirable fatty acid profiles for the wide range of food and industrial product applications.

- Assess the size of the market opportunity and profit potential for specific oil profiles.
- Select the most appropriate crop kinds for specific oil profiles.
- Have freedom to operate relative to patented varieties and technologies.
- Develop specialty varieties with crop yields and other agronomic traits that are fully competitive with varieties having normal fatty acid profiles.

4.6.1 Normal Genotypes

Canada produces significant quantities of canola in Western Canada and Ontario and soybean in Ontario. Since its development, canola production has increased to become the largest source of oil and fat in Canada. Being competitively priced and a domestic source, a preference developed in the 1970s for canola oil in salad oil, margarines and shortenings. Soybean oil use continued in many of these same products. Upon hydrogenation, both canola and soybean oil hardstocks contained trans fats.

Public consciousness about cholesterol and saturated fats in the 1980s afforded opportunities for the canola industry to market canola oil as a low saturate salad and cooking oil. USDA label claims for low saturate on retail salad oil and salad dressings were attractive to US consumers and allowed canola oil to command a premium to soybean oil in US retail salad and cooking oil markets. The US became a very significant export customer of the Canadian industry because of canola oil's low saturate (<7%) content.

With cheaper domestic soybean oil available in the US, the low saturate premium for imported canola oil discourages canola oil from being used as a hydrogenation feedstock for margarine and shortening in that country.

4.6.2 Low Linolenic Genotypes

The Canadian plant biotechnology industry has been investing in the development of low linolenic canola oil for over 15 years. The investment in low linolenic acid genotpyes however has been only a small part of the industry's overall investment in canola breeding as the breeder's research priorities have been on the yield and field performance in canola varieties with a normal fatty acid composition.

Improved oxidative stability and reduced requirements for hydrogenation for oils used in particular food applications, and the resulting fewer trans fatty acids, were recognized to be benefits of the low linolenic acid profile. It is only in the past 5 years that:

- Consensus has been developing on the optimal fatty acid contents within the low linolenic canola genotype for the relative amounts of oleic acid and linoleic acid.
- The yield and field performance of the best low linolenic canola varieties has become reasonably competitive with normal canola varieties.
- Demand for low linolenic canola oil has emerged at the premium price levels needed by crop contractors and processors to expand crop production and oil supply.
- Value chains linking farmers, breeders, crop contractors and processors have developed to aggressively pursue the specialty low linolenic canola business opportunity.

- Breeding investment is expanding by existing and new market players. In February, 2005, Bayer CropScience announced an alliance with Cargill to marry its InVigor hybrid technology with Cargill's high oleic platform. The two companies are aiming to launch a new speciality oil seed onto the market by 2007.[69]

4.6.3 High Stearic Genotypes

Germplasm for high palmitic (C16:0) and high stearic (C18:0) has been developed using mutation and transgenic technologies in several oilseed species.[70,71,72,73] In soybean, high stearic contents have been combined with either high or low levels of oleic acid (C18:1) (Figure 2).

In their natural states, high stearic soybean oils have been found to be unsuitable for spreads because their triglycerides are symmetrical in nature and melt sharply at comparatively low temperatures. However, potential margarine oils have be prepared by blending the high stearic oil with harder components such as tropical fats, interesterified basestocks or soybean/cotton seed stearines. Interesterification of the triglyceride structure raises the melting point and alters the solid fat content to such an extent that high stearic oils can be incorporated into margarines having suitable spreadability, resistance to oil off and sensory properties, i.e. mouth melt.[74]

Dupont has patented a process to fractionate high stearic soybean oil. The solid fraction from the Dupont process with ~40% stearic acid apparently performs very well in confectionary fat products.[75]

> ***Observation:*** *High stearic acid oil profiles in canola, sunflower or soybean might allow Canada to develop an economic domestic supply of plant-based high stearic fats. It is not at all evident that the "optimal" saturated fatty acid profile (whatever that is) should be pursued in each of these crops, for production in Canada or in other countries.*
>
> *For the private industry to invest to develop a high stearic acid profile in even one oilseed crop, the market and profit opportunity for the profile may need to be larger than the Canadian market in order to provide a satisfactory return on investment.*

4.6.4 Timeframe for New Genetics and Yield Improvement

The development of new genotypes and varieties to the point of commercialization is a long and expensive process. There are many risks along the pathway to a new variety, particularly

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69 Cargill and Bayer bring trans fats alternative oil to market. http://www.foodnavigator.com/news/news-ng.asp?id=57746-cargill-and-bayer

70 Qing Liu, Surinder Singh, and Allan Green. "High-Oleic and High-Stearic Cottonseed Oils: Nutritionally Improved Cooking Oils Developed Using Gene Silencing." Journal of the American College of Nutrition, Vol. 21, No. 90003, 205S-211S, 2002. http://www.jacn.org/cgi/content/full/21/suppl_3/205S

71 Martinez Force, Enrique; Munoz-Ruz; Juan; Fernandez Martinez; Jose M.; Garces; Rafael. "High oleic/high stearic sunflower oils." US Patent 6,770,803, 2001.

72 Knutzon, D.S., G.A. Thompson, S.E. Radke, W.B. Johnson, V.C. Knauf, and J.C. Kridl. Modification of *Brassica* seed oil by antisense expression of a stearoyl-acyl carrier protein desaturase gene. Proc. Nat. Acad. Sci. USA 89:2624-2628, 1992.

73 Dharma Kodali. Vegetable Oil Having Elevated Stearic Acid Content. US Patent Application 2004/0166225 A1, 2004.

74 List, G.; Ortheofer, F; and T. Pelloso. "High Stearic acid Soybean Oils and Applications in Food Oil Products". Proceeding 2002 Annual Meeting of the American Oil Chemists Society, 2002.

75 Knowlton, Susan. "Fat Products from High Stearic Soybean Oil and a Method for the Production Thereof". US Patent 6,229,033 B1, 2001.

involving a new genotype, including risks in science, weather, regulation and business. All these risks must be managed, and have a cost. Crop developers must appreciate these risks and costs, and have the management and financial capacity to work through all of them.

As evidenced by low linolenic canola, once the basic science is completed (i.e. the core germplasm identified) and private industry commits to commercialization, it can take firms as long as 10 year or more years to develop the new genotype so the varieties and hydrids marketed to farmers are competitive for contracting and processing. It can take a further 5 years before sales of certified seed grow to the point of profitability.

Table 4 presents a timeframe for genetic improvements to oilseed crops in Canada which might contribute to the reduction of trans fats in food in Canada.

Table 4. Timeframe for Genetic Improvements to Reduce Trans Fats

Crop & Output Trait	Comment	Timeframe for Canada			
		Now	1 – 3 Years	4 – 8 Years	9 – 15 Years
Canola					
Normal	No need to hydrogenate for salad and cooking oil.	X			
Low Linolenic	No need to hydrogenate for salad and cooking oil, spray oil (some applications) and industrial frying oil (some applications). Yield disadvantage to normal canola needing to be eliminated to expand production and use. Once yield exceeds normal profile, low linolenic canola will dominate canola production and retain markets in US.	X	X	X	
High Stearic	Germplasm known. No breeding underway. First varieties at least 5 years away, even with accelerated investment.			X	X
High Erucic	An existing genotype grown, processed and distributed under identity preservation/containment.	X			
New Industrial	New fatty acid profile for industrial use.				X
Soybean					
Normal	Present oil is hydrogenated for the majority of use.	X			
Low Linolenic	US germplasm needing adaptation for Ontario.		X	X	
Sunflower					
Normal	Declining interest in this traditional profile	X			
Mid Oleic	Increasing interest in this profile for light frying use. Germplasm needing adaptation for Prairies.		X		
High Oleic	Niche contract production in US, EU and S. America. Germplasm needing adaptation for Prairies.		X		
Boutique					
Borage	Not hydrogenated and not contributing to trans fats.	X			
Hemp	Not hydrogenated and not contributing to trans fats.	X			

4.7 New Identity Preserved Production

The technical and economic feasibility in Canada of producing, handling and processing 6 – 8 types of fatty acid profiles from canola, soybean and sunflower in Canada is not known.

High oleic, low linolenic genotypes of canola, soybean and sunflower are being contracted with farmers today in Canada and US and are claiming market share from normal genotypes. The ~15% - 20% lower yield of high oleic, low linolenic canola genotypes has made it necessary for Canadian crop contractors to pay farmers a premium of ~$45/tonne relative to normal canola. This premium on a crude oil basis is equal to ~5 cents/pound relative to normal crude canola oil priced at ~30 cents/pound.

Adding to the premium paid to farmers are costs to segregate the specialty canola in grain elevators and at crushing plants, segregate the oil in bulk oil terminals and oil refineries, and to store and ship small lots of both seed and oil. Any costs that are incurred at early stages of the value chain compound and multiply with each subsequent stage of processing. The result can be a very expensive refined oil with a greatly reduced number of places where the product might fit into food formulations. Eliminating the yield disadvantage of the specialty genotypes is critically important to expanding supply and market use.

This cost scenario is the same in high erucic canola which is grown for industrial oil use, and for high oleic sunflower and high oleic soybean which are grown primarily for food use. High stearic soybean, sunflower and canola genotypes have a potential role in the solution to trans fats. Assuming that an "optimal" proportion of saturated fatty acids combined with unsaturated fatty acids is agreed, the oilseed industry could be facing the need to handle 1 – 3 new specialty oil value chains based on high stearic oils in different oilseed species.

> ***Observation:*** *The number of combinations of desirable fatty acid profiles, crop kinds, and end-use applications is possibly far greater than can be supported practically by the Canadian food system. Some specialization of oilseed production will be needed and will occur, particularly if export markets for the specialty oilseed or oil are pursued.*

4.8 Regulation

In bringing forward alternatives to trans fats, the food industry will need to be very cognisant of the regulations in Canada for novel foods and new crop varieties. New genetic events, new varieties with novel traits, new ingredients with novel traits, and new processes that change the composition of food will all be subject to some level of regulatory review.

The principal regulatory areas for industry attention relative to bringing new zero or low trans fat foods to market will be:

- Novel foods – administered by Health Canada.[76]
- Environmental release of plants with novel traits – administered by the Plant Biosafety Office of the CFIA.[77]
- Registration of new varieties and hybrids of oilseeds – administered by the Seed Section of the Plant Product Division of CFIA.[78]

The regulatory system has the strong support of consumers and industry. However, regulation imposes costs which directly impact the industry's profitability and international com-

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[76] Health Canada. Novel Foods and Ingredients. http://www.hc-sc.gc.ca/food-aliment/mh-dm/ofb-bba/nfi-ani/e_novel_foods_and_ingredient.html
[77] Canadian Food Inspection Agency. The Regulation of Plants with Novel Traits in Canada. http://www.inspection.gc.ca/english/plaveg/bio/pntchae.shtml
[78] Canadian Food Inspection Agency. Variety Registration. http://www.inspection.gc.ca/english/plaveg/variet/vartoce.shtml

petitiveness. So, while supporting the regulatory environment, industry should be expected to object to unnecessary regulation.

Regulation also has the potential to raise the entry barrier to new firms, stifle product innovation and slow the commercialization of new technologies. Canadian plant breeders know for example that variety registration is more arduous in Canada than in the US. As a result, it can take plant breeders longer and require more investment to release a new variety in Canada than in the US.

Multi-stakeholder consultations concerning variety registration[79], plant breeders rights[80], and plant molecular farming[81] are posted on the CFIA website. These should be considered relative to advancing solutions quickly to the trans fat issue.

5. Innovation Opportunities

5.1 Fat Replacement in Foods

There are numerous opportunities in developing fat replacers for specific fat functionalities. Many approaches are available to mimic fats and achieve the lubricity, smooth texture, and mouthfeel characteristic of traditional high fat products. As trans fatty acids are often needed to achieve the required functionality in bakery products, the use of emulsifiers to reduce or eliminate fat in the formulation will result in reduced trans content.[82] Danisco has identified the use of emulsifiers as a major strategy in the reduction of trans fatty acids in its products.

Other firms are investigating the use of emulsifiers as structuring agents to eliminate the need for saturated and trans fatty acids in typical hardstocks or in edible spreads. Essentially, these are gels which mimic the texture imparted by fats, and therefore can be used in the manufacture of low-fat or low-trans and low-saturates edible spreads.

Flavour delivery techniques, such as microencapsulation, may also be used in replacing fats as flavour carriers.

5.2 Nutraceutical Lipids

Structured lipids produced by interesterification are used in fat emulsions for total parenteral nutrition and enteral administration. They can be designed to contain a desirable balance of short, medium and long chain fatty acids than meets a certain nutritional requirement.[83] Reduced calorie fats can also be produced because of differences in the absorption and physiological response of short, medium, and long chain TAGs.

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[79] Canadian Food Inspection Agency, Plant Products Directorate, Plant Production Division. Variety Registration. http://www.inspection.gc.ca/english/plaveg/variet/vartoce.shtml

[80] Canadian Food Inspection Agency, Plant Products Directorate, Plant Production Division. Platn Breeders' Rights Office. http://www.inspection.gc.ca/english/plaveg/pbrpov/pbrpove.shtml

[81] Canadian Food Inspection Agency, Plant Products Directorate, Plant Biosafety Office. Plant Molecular Farming Consultation. www.inspection.gc.ca/english/plaveg/bio/mf/mf_cnsle.shtml.

[82] Jay Sjerven . Targeting Trans Fats. Baking & Snack, August 1, 2003. http://www.bakemark.com/TargetingTransFats.htm

[83] Osborn, H. T. and C. C. Akoh. "Structured lipids: Novel fats with medical, nutraceutical, and food applications." Crit. Rev. Food Sci. Food Safety 1: 93, 2002.

Blends of milkfat and corn oil have been interesterified, resulting in a spreadable tablespread with higher content of ω-6 fatty acids than is typical of butter.

> **Observation:** *This demonstrates the potential for interesterification to alter both the nutritional and physical functionality of fats and oils, and to provide novel types of fats and oils beyond those needed to address the trans fat issue alone.*

5.3 Membrane Technologies

The recent advances in membrane technology may provide opportunities for using membrane reactors to immobilize highly specific and fast homogeneous catalysts. This would solve the problem of separating and recovering the oil-soluble catalysts from the reaction mixture. Membrane processes have not been explored commercially by edible oil processors, primarily because many of the processes require that the oil be present as a solution in a solvent (for example hexane), and earlier membranes were not resistant to hexane. (Oil is recovered from the seed as a hexane solution, which is called miscella).

> **Observation:** *With research results indicating the possibility of miscella degumming and miscella refining, a complete membrane based process, carried out in solution, including oil extraction, purification, interesterification and hydrogenation may be feasible, and would completely revolutionize the way edible oils are processed.*

5.4 Novel Hydrogenation

Electrochemical approaches to hydrogenation have been proposed. One method employs a solid polymer electrolyte (SPE) reactor, similar to that used in H_2/O_2 fuel cells.[84] Hydrogenated soybean oil products had a low percentage of total trans isomers (4 - 10%). A preliminary economic analysis of the SPE reactor apparatus suggested the method might be cost-competitive with traditional oil hydrogenation schemes, and commercial-grade products could be prepared by blending low trans, electrochemically hydrogenated oils.

Enzymatic hydrogenation might also be considered using enzymes and pathways such as used by rumen microorganisms to produce oils of varying degrees of unsaturation.[85]

5.5 New Types of Food Products

There are numerous alternatives for the heat treatment of food products, such as extrusion. These processes are fundamentally different from traditional cooking, frying and baking, and will result in products that are completely different from traditional food products. Combination of different unit operations might be used to develop products that reproduce some or all of the functions of traditional products, and can lead to many new unique food prod-

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[84] Hengbin Zhang, Maria Gil, Peter N. Pintauro, Kathleen Warner, William Neff, and Gary List. The Electrochemical Hydrogenation of Soybean Oil with H_2 Gas. http://www.aocs.org/archives/am2000/am2000tp.asp

[85] Loor, J. J., A. B. P. A. Bandara, and J. H. Herbein. 2002a. Characterization of 18:1 and 18:2 isomers produced during microbial biohydrogenation of unsaturated fatty acids from canola or soybean oil in the rumen of lactating cows. J. Anim. Phys. Anim. Nutr. 86:422–432.

ucts. Rapid development of these technologies require a better fundamental understanding of the kinetics of underlying processes.

6. Closing Remarks

Reducing or eliminating trans fats in the Canadian diet will be transforming for the Canadian as well as the global food industry. There are no drop-in solutions that can easily be applied at just one level of the industry in order to effect total change. The transformational change that is needed is systemic and involves a multitude of technical solutions, a multitude of players and the support of consumers.

The industry has made considerable progress to reduce trans fats in many products, and is striving to bring forward zero or low trans fat solutions for all food products. There are challenges that remain, but these are surmountable with investment, time and learning.

Significantly, the leading technologies being introduced converge modern food and nutrition science with the mutation breeding and transgenic technologies of modern bioscience and innovative process engineering.

The basic nutrition research and plant breeding supporting some of these developments have been under study for as long as 30 years. The investment to date has been substantial, initially by public institutions, and commencing ~ 15 years ago, increasingly by industry in Canada and elsewhere.

Equally important, the core technologies now being commercialized appear to have commercial potentials for new products and new foods that address issues far beyond the trans fats problem. The long-term benefits of new food innovations are potentially greater than those identified at present for trans fat mitigation.