TRANS-FREE FATS AND OILS: CHEMISTRY AND CONSUMER ACCEPTANCE

by

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Abstract

Research has shown that *trans* fat consumption increases the levels of low-density lipoprotein (LDL) and has a direct correlation to the incidence of heart disease. It is now widely believed that *trans* fat intake adversely affects the health of consumers. A Food and Drug Administration (FDA) ruling, effective January 1, 2006, required declaration of *trans* fat content on all Nutrition Facts labels of food products. Around the same time local governments, such as the city of New York, and some restaurants followed suit by eliminating *trans* fats from their menus. The food industry's initial concern with *trans* fat elimination/reduction was the loss of some functionality such as shelf life, stability, and creaming ability with *trans*-free fats and oils. Researchers are working to develop new *trans*-free fats and oils that do not have negative sensory properties and maintain the functionality of traditionally hydrogenated oils when used in baked and fried goods.

This is an overview of the chemistry, health risks, and research that has been performed to either reduce or eliminate *trans* fats in food products.

Keywords: Frying, Baking, *Trans* fat, Hydrogenated, Interesterification, Cookie Spread

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Dedication

I would like to dedicate this to all of my friends, family, and coworkers who have supported and inspired me during this journey. Earning a masters degree online poses a unique set of challenges and stressors and I wasn't always the easiest person to get along with after long nights of studying. Therefore I'd like to say thank you for your words of encouragement and gifts of snacks and caffeine. Most of all, I'd like to thank my husband who has stuck with me through all of my educational journeys, from freshman year of high school to the completion of my masters degree. Thank you and I love you!

Preface

This paper is intended to provide an overview of the roles that *trans* fats play and the effects of *trans* fat elimination in the food science and culinary industries. I chose this topic because of my interests in ingredient functionality and current events. I earned my bachelor's degree in culinary science and I work in The Better Homes and Gardens Test Kitchens so I am very interested in the culinary industry as well as food science.

Trans fat elimination is a complex topic that involves an understanding of food quality, food chemistry, and sensory evaluation and I have tried to highlight all of these areas. As I dove deeper into this topic, I realized that the two industries most affected by *trans* fat elimination are the frying and baking industries so I focused my research on these areas.

My hope is that you find this report to be a useful resource on the topic.

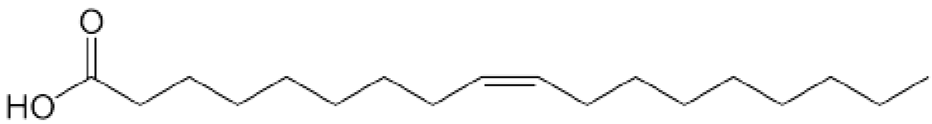
Chapter 1 - Introduction

The culinary industry has always valued the use of *trans* fats in their products because of the fat's ability to increase the shelf life of food items and because *trans* fats are more shelf stable than their unsaturated counterparts. But in the early 1990s *trans* fats came under the national spotlight when consumers were told they were "bad fats" (U.S. Food and Drug Administration 2003). *Trans* fats developed a "bad" reputation because research indicated that they increased the levels of low-density lipoprotein (LDL), which is the undesirable form of cholesterol. This association also supported research that showed that *trans* fat intake had a direct correlation to the incidence of heart disease (American Heart Association 2008). It is now widely believed that *trans* fat intake adversely affects the health of consumers. The research showing this adverse health affect prompted local and national governments to regulate how much of these fats can be allowed in certain products. The food industry relies heavily on fats and oils as a main constituent in baked and fried products, but many *trans*-free oils and shortenings cause the foods in which they are used to have undesirable characteristics such as lumpy and tough crusts, poor flavor, excess spreading in cookie dough, and reduced stability (Daniel et al. 2005).

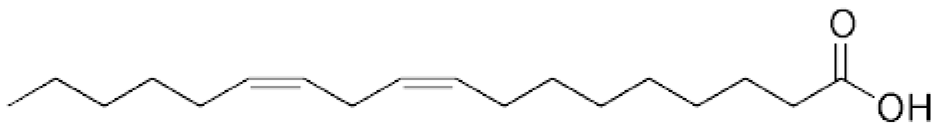
Chemistry of Fats

By definition, a triglyceride is composed of glycerol and fatty acid chains (Semma 2002). These fatty acids can be saturated or unsaturated. Furthermore, unsaturated fatty acids can be classified as monounsaturated or polyunsaturated based off the number of double bonds present (Figure 1.1).

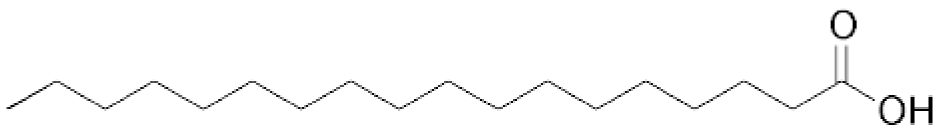
Figure 1.1 - Monounsaturated, polyunsaturated, and saturated fatty acid structures



Monounsaturated fatty acid (Oleic acid)



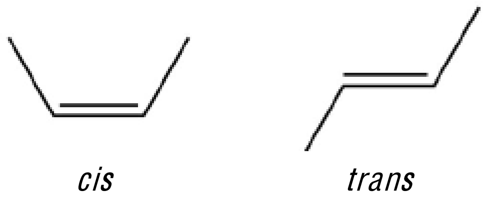
Polyunsaturated fatty acid (Linolenic acid)



Saturated fatty acid (Stearic acid)

These double bonds can be classified as either *cis* or *trans* (Figure 1.2). A *cis* configuration means that the hydrogen atoms are on the same side of the double bond, resulting in a bend in the fatty acid chain. A *trans* configuration has the hydrogen atoms on opposite sides of the bond, resulting in a linear fatty acid chain. *Trans* fatty acids, because they are linear, can pack together more closely resulting in a higher melting point for the fat. In general, fats that contain a large number of saturated fatty acids tend to me more plastic, or solid, at room temperature than fats that contain a large number of unsaturated fatty acids, also called oils.

Figure 1.2 – Conformations of *cis* and *trans* fatty acids



The food industry values saturated fats for the functionality they provide such as increased shelf life, stability at high temperatures, higher melting points, and flavor stability (Tarrago-Trani et al. 2006). Unsaturated fats, which are more prone to oxidation, can be converted to saturated fats via a process called hydrogenation in which a fat is heated in the presence of hydrogen gas and a catalyst. The double bonds on the unsaturated fatty acids react with the free hydrogen and become saturated. *Trans* fats are formed when double bonds with a *cis* configuration open up in the presence of hydrogen and reform as a *trans* double bond (Ackman and Mag 1998).

Current Technologies

Hydrogenation Techniques

Although the hydrogenation process is responsible for a majority of the *trans* fats found in food fats, this process can be altered in various ways resulting in decrease in *trans* fatty acid production. One technique involves more selective catalysts that can either prevent the formation of *trans* or promote the formation of *cis* stereoisomers (Wright et al, 2003; Higgins). These catalysts are generally made of nickel, palladium, or a combination of the two metals (Mondal and Lalvani 2000; Lalvani and Mondal).

Other modifications to the hydrogenation process involve stricter reaction conditions such as lower temperatures, modified gas atmospheres, and altered pressures (List et al. 2007). A common technique resulting in reduced *trans* fat byproducts is called electrochemical hydrogenation. In this process, the hydrogen atoms are supplied by either hydrogen gas or water. The free hydrogen is then electrochemically oxidized into H+ ions and electrons. The double bonds that are present in unsaturated fatty acids react with the hydrogen gas reduction products and the oil becomes hydrogenated with minimal *trans* fat production (List et al. 2007).

Interesterification

Interesterification is generally used to produce shortenings and margarines with desirable functionality and taste but contain no *trans* fatty acids (List et al. 1995). During this process, the ester bonds between the glycerol backbones and fatty acid chains are hydrolyzed. The ester bonds then reform between the mixed fatty acids and glycerol backbones. This process allows manufacturers to produce customized fats for various food applications. Interesterification can be performed either chemically or enzymatically (Strayer et al. 2006).

Chemical interesterification is a mostly random process resulting in a somewhat controlled composition of triglycerides. First, the desired oils in predetermined amounts are blended and dried. Next a chemical catalyst such as sodium methoxide is added. The reaction takes place under controlled conditions. Finally, the catalyst must be neutralized and the oil cleaned and deodorized (Strayer et al. 2006).

When more control is necessary, enzymatic interesterification can be used. In this process microbial lipases are added to the mixed species of triglycerides. These lipases selectively act on specific ester bonds resulting in more precise final triglyceride compositions. Two downfalls of this technique are the amount of time required for the reaction to take place which may take hours or even days and the need for more controlled reaction conditions (eg, temperature and pH) (Kellens 2000; Bierschbach et al. 2004).

Plant Breeding/Genetic Engineering

The fatty acid profile of a vegetable oil can be altered using genetic modifications and controlled growing conditions. Genetic modifications can be achieved either through conventional or molecular plant breeding. Soybean cultivars are commonly altered to yield oils with desirable flavors and stabilities while containing lower *trans* fat levels than their wild type counterparts (Olivia et al. 2006). Vegetable oils that are more stable will require less hydrogenation.

Nutritional Impact of *Trans* Fats

Over twelve million people die each year from cardiovascular disease which is currently the leading cause of death in both the United States and Europe (British Heart Foundation Statistics 2012; Centers for Disease Control and Prevention 2012). Many epidemiological studies have shown a causal relationship between the consumption of saturated fats and the presence of high cholesterol and coronary heart disease (Keys 1980; Kromhout and de Lezenne 1984; Caggiula et al. 1997). A study performed by Mensink and Katan (1990) indicated that *trans* fatty acid consumption resulted in increased low-density lipoprotein (LDL) cholesterol, the undesirable cholesterol, and decreased high-density lipoprotein (HDL) cholesterol, the good cholesterol. It has been demonstrated that by replacing only 5% of a person's typical calorie intake of saturated fatty acids with *cis*-unsaturated fats, coronary heart disease (CHD) risk would decrease by 42%. Also, replacing 2% of a person's typical calorie intake from *trans* fatty acids with *cis*-unsaturated fats yields a 53% decrease for CHD (Hu et al. 1997).

A Harvard School of Public Health study focused on the link between the concentration of *trans* fatty acids in red blood cells and the associated risk of CHD. Between the years of 1989 and 1990 blood samples were collected from 32,826 female nurses across the United States. Over the next 6 years, 167 of the subjects experienced a nonfatal heart attack. To analyze the data, researchers paired 2 control subjects with each disease case. This study relied on biomarkers rather than dietary questionnaires to analyze the test subjects levels of *trans* fat consumption so that the data wouldn't be dependent on accuracy of dietary reporting. The study showed a nearly threefold increase in the risk of CHD between the bottom and top quartiles of *trans* fatty acid concentrations in red blood cells. This clinical study provides further evidence linking *trans* fat consumption and CHD (Sun et al. 2007).

Trans fatty acids also have been shown to compete with *cis*-fatty acids causing an inhibition of the incorporation of these fatty acids into membranes, altering omega-3 and omega-6 fatty acid metabolism, and affecting various other biosynthetic pathways (Hu et al. 2001; Valenzuela et al. 1999; Mann 1994). Furthermore, positive associations between *trans* fat consumption and allergic responses such as asthma, sinus allergies, and atopic eczema (Weiland et al. 1999). Based off of these findings, health organizations and governments have implemented regulatory initiatives on *trans* fat contents and labeling (Federal Register 1999).

Table 1.1 – *Trans*-Fatty-Acid Content of Foods Analyzed by Gas-Liquid Chromatography (adapted from Litin and Sacks 1993).

Food	***Trans* Fatty Acids (g)**[a]
Animal products	
Beef (5 oz)	0.90
Butter (1 tsp)	0.10
Chicken (5 oz)	0.10
Pork (5 oz)	0.10
Vegetable fats	
Reduced-calorie mayonnaise (1 tsp)	0.01
Soft margarine (1 tsp)[b]	0.27
Stick margarine (1 tsp)[b]	0.62
Vegetable oil (1 tsp)[b]	0.02
Vegetable shortening (1 tsp)	0.63
Commercial and fast-food products	
Cake (1 piece)[b]	1.04
Cookies (1)[b]	0.86
Corn chips (1 oz)[b]	1.42
Crackers (1)[b]	0.12
Doughnuts (1)	0.44[d], 3.19[e]
French Fries (4 oz)[c]	2.41, 3.43
Pie (1 piece)[b]	1.00
Pizza (1 slice)[b]	0.13
Potato chips (1 oz)[b]	0.11

[a]One to 10 samples of each food were analyzed

[b]Composite sample of several brands

[c]Values represent samples from two different fast-food stores

[d]Package information lists beef shortening as a fat possibly used

[e]Package information lists only vegetable fats among the ingredients

Many vegetable oils with high levels of polyunsaturated fatty acids have to be hydrogenated to allow for stability and extended shelf life. The concern with hydrogenation is that this process is responsible for about 75% of the *trans* fat content in oil (Daniel et al. 2005). Research is being performed, however, to develop new *trans* fat-free products that do not have negative sensory properties and are shelf-stable when used in baked and fried goods. The following studies review in this paper were conducted to compare commercially available oils and evaluate them based on sensory ratings, chemical analyses, and nutritional profiles to determine if there were statistical differences between oils containing *trans* fats and ones that were *trans*-free. The purpose of this literature review is to highlight research that has been conducted on *trans* fat elimination in the food industry and reveal areas that require further exploration.

Chapter 2 - Review of Literature

Trans Fats in Food Systems

The food industry relies on various fats for both their ingredient functionality and frying capabilities. The high temperatures involved in frying allow for rapid heat transfer from the oil to the food resulting in a dehydration reaction. This rapid dehydration yields a crisp, golden crust on the exterior of the food being fried. The concern with frying is that during this process the elevated temperatures, generally above 190°C, and extended processing times, repeated heating of the oil, initiate an isomerization reaction of the polyunsaturated fatty acids and thereby create *trans* fats (Wolff 1993, Aladedunye et al. 2009). A study by Przybylski and Aladedunye (2012) looked specifically at baking and stir-frying to determine if *trans* fats were created during the actual cooking process. They determined that under normal conditions, baking and stir-frying do not accelerate the isomerization of polyunsaturated fats like in frying.

Besides frying, the other industry heavily impacted by the new *trans* fat regulations is the baking industry. Stability is a major concern with frying oils while the physical characteristics of oils and shortenings are the most important factor in baking. In a dough system, fats and oils play various functional roles including stabilizing air cells, acting as a lubricant, limiting gluten development, and tenderizing the dough (Given 1994; Maache-Rezzoug et al. 1998). In cookie doughs, shortenings are used most commonly due to their ability to incorporate air bubbles into the system when creamed with sugar (Abboud et al. 1985). The problem is that shortenings are hydrogenated and most often contain significant levels of *trans* fats. When reformulating frying recipes, researchers are most concerned with the oil's stability and product's sensory acceptance while bakers are most concerned with the rheology of the fat.

Effects of *Trans* Fat Elimination in Frying

Analysis of Commercially Available Frying Oils

A study by Bordi, Hack, Rager, and Hessert (2010) analyzed the sensory characteristics of doughnuts fried in various commercially available shortenings. The shortenings that were analyzed were a *trans* fat-free canola shortening, a *trans* fat-free palm shortening, and a hydrogenated vegetable oil that contained *trans* fats. The raw yeast doughnut dough used in the study was prepared at a local grocery store and then transported to the laboratory for frying and analysis. Doughnuts were fried in each of the three oil types for three separate sessions. Half of the doughnuts were immediately iced after frying and evaluated by sensory panelists. The other half of the doughnuts were immediately cooled, packaged, and frozen for ten days. After the ten day freezing period, the doughnuts were warmed to 120°F, iced, and then evaluated by sensory panelists (Bordi 2010).

The doughnuts were assigned random three-digit numbers and served to 167 untrained, volunteer panelists recruited from the university. Panelists were asked to evaluate the doughnuts taste, texture, color, appearance, moisture content, and overall liking by using a 7-point "Just About Right" (JAR) scale and a 7-point hedonic scale. On average, panelists preferred the doughnuts fried in palm oil when sampling freshly fried doughnuts. When sampling the frozen and reheated doughnuts, panelists preferred the doughnuts fried in canola oil. In five of the seven categories analyzed by panelists, a *trans*-free shortening scored higher than the *trans* fat containing vegetable oil. In fact, both *trans*-free shortenings performed better than the *trans* fat oil in three of the categories (preference, appearance, and moisture content) (Bordi 2010).

This study demonstrated that *trans* fat-free, commercially available shortenings were acceptable alternatives to the traditional *trans* fat containing frying oils used in bakery frying applications. (Bordi 2010). The study did not address the concerns raised by the other segment of the baking industry that uses fats for their functionality as an ingredient.

Hack, Bordi, and Hessert (2009) also evaluated the sensory characteristics and performance of readily available low *trans* oils used to fry French fries. These oils were compared to ones containing *trans* fats. The oils in the study were grouped into two categories: heavy duty (HD) and general purpose (GP). The HD oils were *Crisco Professional*® Heavy Duty Creamy, Amaizing Fry™, Mazola® ZT, FryMax®, and Pour'n Fry®. *Crisco Professional*® Heavy Duty Creamy, Amaizing Fry™, Mazola® ZT had the lowest levels of trans at 0.3, 0.3, and 2.8%, respectively. HD oils are vegetable oils that have been extensively refined and blended with hydrogenated oil and generally perform better in frying applications. The GP oils were *Crisco Professional*® General Purpose Creamy and Advantage® Creamy *Trans* Solution which were both low in trans with 0.6 and 0.5%, respectively. These oils are produced in a similar manner as the HD oils except that they are blended with fully hydrogenated oils, which yield superior taste qualities and stability (Hack et al. 2009).

The researchers degraded the oils over a period of ten days by frying 90 pounds of frozen French fries daily. As the oil level in the fryers decreased, fresh oil was added to top them off. During the ten days of the oil degradation experiment, sensory analysis was conducted on the French fries. Fries were served to university students and community members for evaluation. Samples of the fries cooked in the various oils were randomly presented to the participants and were served immediately after frying. Panelists evaluated the fries on taste, texture, and color using a seven-point liking scale. Tables 2.1 and 2.2 illustrate the results of the sensory evaluations. Based on average ratings across the ten days of sensory evaluation, FryMax® received the highest rating for overall acceptability in the HD creamy category. For the GP creamy category, the *Crisco Professional*® General Purpose Creamy showed a slightly higher rating. Researchers did indicate that no significant differences existed between the means for liking on any given sensory day. Statistical analysis also showed that the there were no significant differences in mean scores for the acceptance of appearance of the fries, acceptance of color of the oil, and acceptance of texture of the fries between the oils containing high levels *trans* fats and those that contained low levels (Hack et al. 2009).

Table 2.1 - Overall liking of French Fries fried in HD creamy oils (based on seven-point Hedonic scale[a]) (Hack et al. 2009).

	Overall Liking					
Oil	Day 2	Day 4	Day 6	Day 8	Day 10	Average
Crisco Professional® Heavy Duty Creamy	5.53	5.44	5.27	5.27	5.33	5.33
Amaizing Fry™	5.31	5.37	5.28	5.43	5.41	5.36
Mazola® ZT	5.44	5.43	5.16	4.92	5.2	5.23
FryMax®	5.48	5.44	5.35	5.79	5.36	5.48
Pour'N Fry®®	4.86	5.05	5.33	4.92	4.85	5.06

[a]Seven-point Hedonic scale: 1 = dislike very much; 2 = dislike moderately; 3 = dislike slightly; 4 = neither like nor dislike; 5 = like slightly; 6 = like moderately; 7 = like very much

Table 2.2 - Overall liking of French Fries fried in GP creamy oils (based on seven-point Hedonic scale[a]) (Hack et al. 2009).

	Overall Liking					
Oil	Day 2	Day 4	Day 6	Day 8	Day 10	Average
Crisco Professional® General Purpose Creamy	5.20	5.32	5.46	5.00	5.25	5.25
Advantage® Creamy *Trans* Solution (180)	5.15	5.16	5.15	5.29	5.32	5.21

[a]Seven-point Hedonic scale: 1 = dislike very much; 2 = dislike moderately; 3 = dislike slightly; 4 = neither like nor dislike; 5 = like slightly; 6 = like moderately; 7 = like very much

Peroxide values were analyzed for the oils across the ten days of degradation. The study showed that the FryMax® oil had the greatest level of oxidation and degradation. The Pour'n Fry® and *Crisco Professional*® General Purpose Creamy oils showed a negative degradation value over the ten days, meaning these oils were not oxidized. FFA values showed that the greatest percentage increase, or greatest degradation, occurred in the oils containing high levels *trans* fats. The low *trans* oils showed the least amount of degradation. Researchers also analyzed the performance of these oils by testing the free fatty acid (FFA) content and food-to-oil ratios. These data were analyzed using analysis of variance (ANOVA) (Hack et al. 2009).

Overall, this study indicated that the level of *trans* fats present in a frying oil had no effect on the sensory panelists ratings. Furthermore, analytical testing revealed that they are viable alternatives because of their stability and shelf life (Hack et al. 2009). This study utilized an untrained panel to analyze the sensory characteristics of the fries, but the researchers did not address whether or not a trained panel would be able to detect subtle differences.

Analysis of Novel Frying Oils

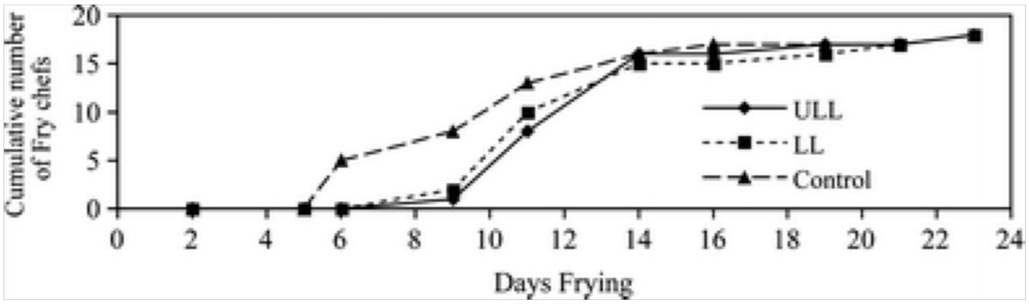
In a similar frying study, researchers and trained sensory panelists analyzed the properties and performance of a newly developed soybean oil (Gerde et al. 2007). Their study showed that decreasing the amount of *trans* fats in frying oils reduced the stability and fry life of frying oils. This study also indicated which factors may contribute to the stability and fry life of the soybean oils tested.

The soybean cultivars used in this study were originally developed at Iowa State University (ISU) for the two oils being tested. Three types of fatty acid compositions were tested including the control. The first was the ultra low-linolenic acid oil, known to consumers as Asoyia, which had the lowest percentage of linolenic acid at 1.5%. The second was the low-linolenic acid oil (LL), which had 2.6% linolenic acid. The third, which was the control oil, had 5.3% linolenic acid. The frying materials used for this experiment were commercial extra-long par-fried French fries. The manufacturer had par-fried them using various types of oils, which could have included partially hydrogenated vegetable shortening made from canola, soybean, palm, and/or beef fat. Other compounds that were present in the fries were dihydrogen pyrophosphate (to promote color retention), dextrose, and natural flavoring (Gerde et al. 2007).

The method used to test the heat stability of the oils was frying. The test was conducted by frying batches of French fries for 6 hours per day in a commercial setting. Each of the three oils was replicated twice for a total of 6 deep-fat frying trials. This test was conducted over the course of 23 days. The temperature of the frying oil was 190°C prior to the addition of the fries. Once the frozen fries were added, the temperature dropped to 165°C and at the end of frying the oil reached a recovery temperature of 175°C. The temperature was monitored and recorded every 30 seconds throughout the frying process. At the end of every day, a fast flute shortening filter was used to filter the oil and remove food particles. Samples of the oil were taken and placed in a jar for further evaluation. To prevent further oxidation, the oil was kept in a dark environment under nitrogen atmosphere at a temperature of 22°C. During the testing, the oil was examined for changes in stability by evaluating differences in sensory characteristics such as color and flavor (Gerde et al. 2007).

During the operation, 9 trained frying chefs from the ISU dining center were used to evaluate the oils using a scoring sheet. Two observations, one for each of the replicates, were recorded by each chef on the evaluation days. The chefs evaluated the oils on days 2, 5, 11, 14, 16, 19, 21, and 23. Each chef judged the unidentified oils independently to determine when the oils should be changed. The chefs' final decision for evaluating when the oil needed to be changed for both replicates was on the 23rd day (see Figure 2.1). So that the composition of the fatty acid methyl esters (FAME) could be determined, each oil was analyzed by using gas-liquid chromatography. Oxidation of the oils was calculated after the FAME composition was determined. Gas-liquid chromatography analysis was performed on the oils prior to and throughout the frying process (Gerde et al. 2007).

Figure 2.1 – Cumulative number of fry chefs who judged at least one of the replicates of ultra-low-linolenic acid (ULL), low-linolenic acid (LL) and control soybean oils ready for changing during frying (Gerde et al. 2007).



The sensory evaluations of the French fries were conducted on days 2, 5, and 6. Twelve individuals were trained to determine the flavor attributes of the oils by recognition and quantification. Sensory panelists were required to determine flavor characteristics such as rancid, painty, potato, and buttery flavors. A 15-cm line scale was used to rate the flavor attributes ascending from 0 to 15. For statistical analysis, data were collected and analyzed using SAS software and analysis of variance (ANOVA) results were reported (Gerde et al. 2007).

The results from this study indicated that the oils with the lowest concentrations of linolenic acid had the highest stability. The Asoyia oil had the highest amount of stearic acid and the lowest amount of linolenic acid, giving it the highest stability. The LL oil had an intermediate linolenic acid concentration and the control had the highest amount of linolenic acid, so in theory it was the least stable (Gerde et al. 2007).

When the researchers analyzed the overall FA composition of the oils, they found that the less stable fatty acids decreased in weight percentage during the frying process while the more stable fatty acids increased in weight percentage. A plateau was reached around day nine for the weight percentage changes in the oils. This was most likely due to the oils reaching equilibrium between the rate of turnover and rate of degradation (Gerde et al. 2007).

All of the oils had peroxide values (PV) of less than 1 meq x kg^{-1} which shows that the oils were fresh and unoxidized. The fresh Asoyia and LL oils had oxidative stability indices (OSI) that were higher, or more stable, than the control. The OSI method can only give a prediction of the oils oxidative stability under severe conditions performed in this method. However, the OSI cannot determine the stability of the oils during the deep fat frying of various food systems due to different food compositions (Gerde et al. 2007).

The sensory results indicated that using Asoyia or a low-linolenic acid oil would be beneficial to extend fry life and reduce cost. Sensory panels were conducted and 8 out of 18 of the panelists noted that the control should be changed, one indicated that the Asoyia oil was ready to be changed, and two noted that the LL oil should be changed on day 9. The evaluators consistently indicated that the control oil needed to be changed after day 9 (Gerde et al. 2007).

Using both the Asoyia and the LL oils as an alternative to *trans* fats used in frying had desirable stability characteristics. Panelists indicated low levels of off flavors, including painty and rancid ones, when the experimental oils were evaluated. The panelists also noted a low level of buttery flavor. In all of the treatments, the most predominant flavor was potato. Overall, the control received lower ratings than the Asoyia and LL oils in terms of oxidation. The Asoyia and LL oils were shown to be more stable with the Asoyia oil being slightly more stable than the LL oil (Gerde et al. 2007).

In conclusion, both the LL and the Asoyia oils were shown to have sufficient heat and oxidative stability allowing them to be suitable substitutes for traditional hydrogenated oils containing *trans* fats. The control had the highest amount of linolenic acid at 5.3% causing it to be more susceptible to oxidation due to a higher amount of double bonds present. The Asoyia oil had the lowest amount of linolenic acid, was the most stable, and had the least amount of double bonds (Gerde et al. 2007).

Analysis of Oil Stability

The previous studies relied heavily on sensory panelists to determine if differences existed among the various oils but did not emphasize the quantitative changes that occur in frying oils over time. Daniel, Thompson, Shriver, Wu, and Hoover (2005) developed a research study to determine the differences among partially hydrogenated canola oil, partially hydrogenated soybean oil, and cottonseed oil and to determine quantitatively if the quality of the French fries and frying oils were affected over time.

The researchers started with frozen French fries containing four grams of total fat and one gram of saturated fat. The fries were weighed and then cooked in batches at 177°C for five minutes. On day one of the study, 18 batches of fries were cooked in total, six batches per oil type. This process was repeated for the following four days so that all oils had undergone heating and frying for five consecutive days. Oil samples were prepared by allowing one drop of oil to equilibrate with approximately 1.5mL of a methylation mixture in a septa-sealed vial. The oil samples and French fries were then analyzed by Texas A&M's Agricultural Extension Center and Analytical Food Laboratories in Grand Prairie, TX. Quantitative analyses were performed by injecting one microliter of headspace gas of the equilibrated oil into a gas chromatograph programmed to 240°C. The data were statistically analyzed using SAS software with the dependent variables being color of the French fries and oil, weight of the fries, and loss of oil (Daniel et al. 2005).

The researchers could not find any significant differences concerning the fat content of the French fries cooked in the different oils. The frozen fries contained approximately 4.1% fat initially, but by the time the fries were cooked that value increased to 11.4%. It was also determined that adding fully frozen French fries as opposed to slightly thawed fries to the fryers reduced the overall absorption of oil although the amount wasn't specified. Also, as oil was used and reheated on a daily basis, it began to break down due to oxidation. This breakdown of oil allows it to be absorbed more readily by foods. Previous studies had also shown that repeated use of oil increases the fat content of the oil. An interesting result in this study concerned cottonseed oil because the amount of saturated fat in the oil decreased as it was used more. The researchers then analyzed the *trans* fat content of the oils and fries paying special attention to the cottonseed oil. The results, illustrated in Table 2.3, indicated that of the three oils, the *trans* fat content of the cottonseed oil was significantly lower than in the canola and soybean oils. For this particular study, the researchers determined that cottonseed oil was the best choice in cooking oils as far as *trans* fat content was concerned (Daniel et al. 2005).

Table 2.3 – Fatty acid composition (wt/%)[a] of cottonseed oil, canola oil, and soybean oil on trial days 0, 1, and 5 (Daniel et al. 2005).

	Cottonseed Oil (Days)			Canola Oil (Days)			Soybean Oil (Days)		
Fatty acids[b]	**0**	**1**	**5**	**0**	**1**	**5**	**0**	**1**	**5**
Saturated	24.36	24.07	23.50	9.35	9.23	10.73	14.48	13.68	16.31
Monounsaturated	19.68	21.57	29.36	78.03	77.15	75.18	60.43	60.85	52.78
Polyunsaturated	55.96	54.36	47.15	12.62	13.62	14.10	25.09	25.47	30.90
Trans	0.10	1.20[y]	4.97[y]	30.1	21.30[z]	21.17[z]	19.1	20.00[z]	21.10[z]

[a]wt/% - percentage of specific fatty acids based on total weight

[b]16:0 - palmitic acid, 18:0 - stearic acid, 18:1 - oleic acid, 18:2 - linoleic acid, 18:3 - linolenic acid

[yz]Means within a row with different superscripts are significantly different (P<.01); n=18

Effects of *Trans* Fat Elimination in Baking

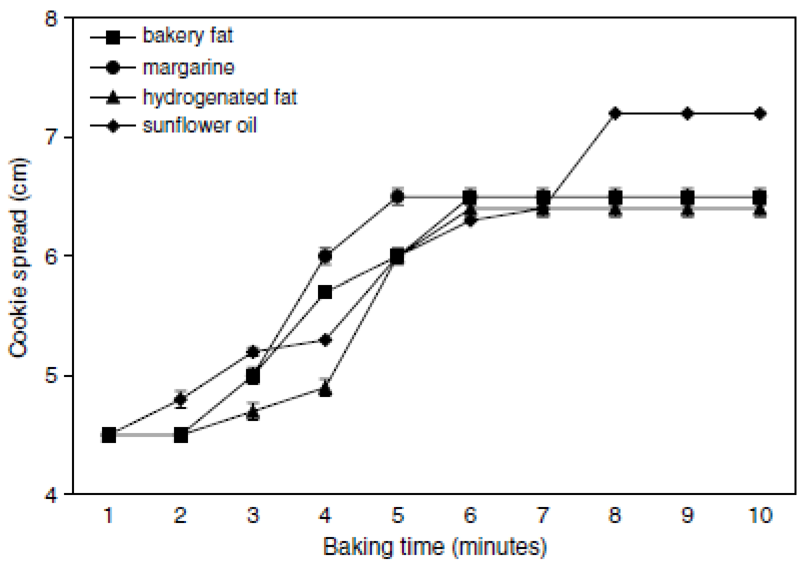
Analysis of Cookie Doughs

Jacob and Leelavathi (2007) conducted a study looking at the rheological and textural characteristics of dough and baked cookies containing either a standard bakery shortening, bakery margarine, non-emulsified hydrogenated shortening (vegetable derived), and a sunflower oil. The sunflower oil contained no *trans* fats.

When analyzing the dough itself, researchers found that while the dough containing sunflower oil was softer and easier to manipulate initially, with continued mixing the dough grew stiffer than the other fats. This can be attributed to the fact that oils do not effectively cream with sugar like more plastic fats can do. Gluten development is less inhibited in doughs containing oils due to improper fat distribution and these doughs often become overworked (Jacob and Leelavathi 2007).

The baked cookies also greatly differed based on the specific fat used. Figure 2.2 illustrates that the sunflower oil cookies showed considerably more spread during baking. The cookies containing the fully hydrogenated fat showed the least amount of spread. As previously mentioned, the use of oil in a cookie dough system leads to improper fat distribution and aeration. The cookie dough's final viscosity is therefore affected and one will see a longer spread time in the oven and greater overall spread when compared to plastic fats (Tsen et al. 1975).

Figure 2.2 – Effect of bakery fat, margarine, non-emulsified hydrogenated fat, and sunflower oil respectively, on the rate of cookie spread (Jacob and Leelavathi 2007).



When analyzed for breaking strength, the sunflower oil cookies were significantly harder than the other cookies, which did not significantly differ from each other. Interestingly, there seemed to be no relationship between the dough hardness and cookie breaking strength based on the fact that the oil and bakery fat doughs had similar dough hardness scores but the oil cookies had the highest breaking strength scores while the bakery fat cookies had the lowest scores (Table 2.4). This can again be attributed to the aeration factor (Jacob and Leelavathi 2007).

White this study revealed the functionality differences between oils and plastic fats in a cookie dough system, one cannot conclude that trans fats play a role in these differences.

Table 2.4 – Effect of fat type on the physical characteristics of cookies (Jacob and Leelavathi 2007).

Fat type	Width (*W*) (cm)	Thickness (*T*) (cm)	Spread ratio (*W/T*)	Breaking strength (kg f)
Bakery Fat	8.1^{b}	1.08	7.51	4.6^{a}
Margarine	8.1^{b}	1.10	7.37	4.7^{a}
Hydrogenated fat	7.8^{c}	1.03	7.58	5.1^{ab}
Sunflower oil	8.8^{a}	1.05	8.38	9.7^{c}

Figures followed by different letters are significant different from each other ($p \leq 0.05$)

Tsen, Bauck, and Hoover (1975) concluded that sodium steroyl lactylate (SSL), when added to cookie doughs, improved overall aeration, viscosity, and grain of the cookies. SSL is an emulsifier and dough strengthener which helps to reinforce the gluten network improving aeration, texture, and volume. When added to the sunflower oil cookies hardness scores were significantly reduced, surface cracking was improved, and amount of spread was reduced (Jacob and Leelavathi 2007). Other studies have alluded to the fact that oils with added emulsifiers perform as well as shortenings in regards to product characteristics affected by dough aeration (Given 1994).

A similar study by Ahmadi and Marangoni (2009) compared cookies containing an interesterified (IE) *trans*-free bakery shortening to cookies made with traditionally hydrogenated shortening. A standardized chewy-style drop cookie recipe was used for the cookie preparation and the only variable was the type of shortening used. The cookies were baked for 10 minutes at 177°C and then cooled completely. Weights, widths, and thicknesses were measured for the cooled cookies. Researchers also measured the breaking strength required for each cookie type.

An untrained panel evaluated the cookie samples one day after they were prepared. Panelists used a standard triangle test intended to identify the odd sample.

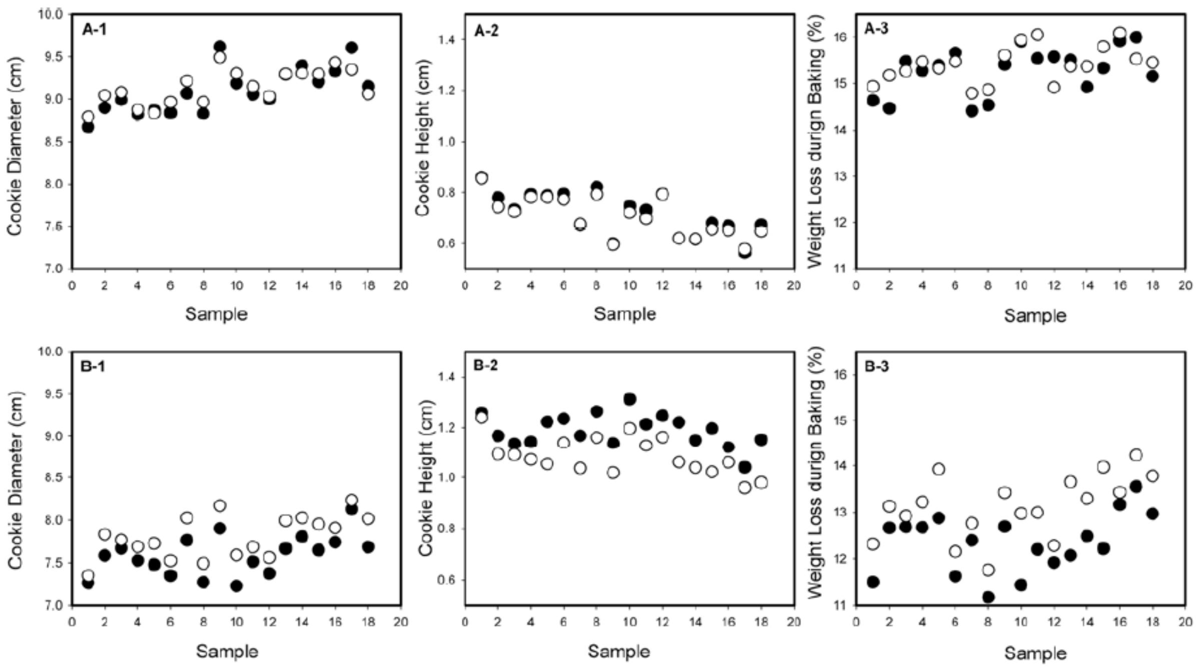
The physical measurements indicated that the cookies made with IE shortening were wider and had more spread than the hydrogenated shortening cookies but that there were no differences in the thickness and harness of the cookies. The sensory results showed that of the 37 panelists only 16 could distinguish between the samples which indicates that there were no statistically significant differences in the sensory characteristics of the cookies. This study confirmed that interesterified *trans*-free bakery shortenings are proven alternatives to traditionally hydrogenated fats (Ahmadi and Marangoni 2009).

In another study, Kweon, Donelson, Slade, and Levine (2010) compared sugar-snap and wire-cut cookies made with both *trans* and *trans*-free shortenings. Cookies were prepared according to American Association of Cereal Chemists (AACC) approved methods and differed only in the type of fat used, flour cultivar, and sugar concentration. The wire-cut cookies were baked for 10 minutes while the sugar-snap cookies were baked for 11 minutes in a 204°C oven. Weights were recorded for dough balls, freshly baked cookies, and cookies after a 3 hour cooling period. Researchers also recorded heights and diameters of the cooled cookies (Figure 2.3).

After statistical analysis of the data, researchers determined that the *trans* fat-free cookies prepared using the wire-cut method had significantly larger diameters, shorter heights, and greater weight losses compared to the *trans* fat cookies. Significant differences were not seen in the cookies prepared with the sugar-snap method. To determine if there were any interactions between the fat type and flour cultivars, Spearman's rank coefficients were calculated. It was determined that there were no significant interactions between the fat types and flour cultivars.

This study showed that wire-cut cookies were more sensitive to formula changes compared to sugar-snap cookies (Kweon et al. 2010).

Figure 2.3 – Cookie diameter, height, and weight loss during baking for sugar-snap (SS) and wire-cut (WC) cookies formulated with *trans*-fat (●) and zero-*trans*-fat (○) shortenings: A-1, cookie diameter for SS cookies; A-2, cookie height for SS cookies; A-3, weight loss during baking for SS cookies; B-1, cookie diameter for WC cookies, B-2, cookie height for WC cookies; B-3, weight loss during baking for WC cookies (Kweon et al. 2010).



Even though a *trans*-free oil or shortening may have the desired functionality needed in a dough system, consumers may not accept a reformulated product. The researchers behind the doughnut frying study also analyzed *trans* fat-free sugar cookies and evaluated various sensory attributes. The cookies only differed in the types of fat used, although the article does not specify which specific fats we used. The two cookie samples were presented to an untrained panel consisting of 151 university students and staff. Using a 7-point hedonic scale, where 1 = dislike very much and 7 = like very much, panelists were asked to rate each cookie for sweetness, appearance, texture, taste, and overall liking (Bordi et al. 2007).

Panelists rated the *trans*-containing sugar cookie higher in terms of appearance while the *trans* free cookie received significantly higher ratings in terms of sweetness. No significant differences were indicated for taste, texture, and overall liking (Table 2.5). Researchers also analyzed the sensory evaluations in terms of gender and age groups. Both college females (18 to 24 years of age) and adult females (25+ years) rated the original cookie significantly higher for appearance. There were no significant differences among the male scores. Gender and age seemed to play no role in the ratings for taste and texture while college males indicated a significantly higher rating of the *trans* free cookie in terms of sweetness. When asked which cookie they preferred, 55.6% of the panelists selected the *trans* fat-free cookie (Bordi et al. 2007). This sensory study indicates a liking of this particular *trans* fat-free sugar cookies.

Table 2.5 – Attribute means of cookie (Bordi et al. 2007).

	Appearance	**Taste**	**Texture**	**Sweetness**	**Overall Liking**
Original cookie	5.97* ± 1.058	5.69 ± 1.066	5.56 ± 1.087	5.44* ± 1.198	5.56 ± 1.186
Trans fat-free cookie	5.52* ± 1.259	5.64 ± 1.318	5.46 ± 1.215	5.70* ± 1.233	5.65 ± 1.223

*Denotes significant difference between samples. Total panelists, n = 151; male, n = 54; female, n = 97.

A final study by Handa, Goomer, and Siddhu (2010) analyzed the performance of interesterified shortening in a cookie application. Researchers refer to the cookies in the article as short dough biscuits having an average height of about 1.2 cm and width of 5.3 cm so I have made the assumption that they are working with cookies. Similar to the Ahmadi and Marangoni

(2009) study, the researchers made two batches of cookies, one with traditionally hydrogenated shortening and one with an interesterified *trans*-free shortening. The cookues were baked at 180°C for 25 minutes, cooled for 1 hour at room temperature, and then packaged for storage until analysis. The diameters and heights were measured to calculate the spread ratio and hardness measurements were obtained from a texture analyzer instrument. Some of the coolies were stored for up to 8 months to evaluate the changes in quality during storage. The quality attributes of interest included moisture content, hardness, and acidity of the fat. Finally, a sensory panel consisting of 10 volunteers evaluated the cookies for flavor, color, texture, appearance, and overall acceptability. Panelists utilized a 9-point hedonic scale with 'dislike extremely' and 'like extremely' as the anchors. A point of concern for this study surrounds the low number of panelists (n = 10) and no indication as to their level of training.

Physical measurements revealed that the cookies made with interesterified shortening yielded significantly larger diameters, shorter heights, and greater spread than those made with traditionally hydrogenated shortening. Because hydrogenated fats have a higher solid fat index, they yield lower amounts of shortening and greater gluten development (Manohar and Rao 1999). In terms of moisture content of the cookies, there were no significant differences among the treatments. Texture analysis results showed that both types of cookies became harder as they were stored but the biscuits made with the interesterified shortening consistently scored as being significantly less hard than the control. Finally, sensory panelists scored the *trans*-free cookies significantly higher in terms of flavor and overall acceptability while the other three attributes (color, texture, and appearance) had similar scores for both samples (Table 2.6). Again there is concern with low number of panelists (n = 10) in this study and no real conclusions can be made based off of these sensory results. Ahmadi and Marangoni's study (2009) revealed the potential of using interesterified shortenings in cookie dough applications and this study by Handa et al. (2010) supports the aforementioned research.

Table 2.6 – Sensory evaluation scores for hydrogenated shortening cookies (HSC) and interesterified *trans*-free shortening cookies (IETFSC) (Handa et al. 2010).

Sample	Color[†]	Flavor[†]	Texture[†]	Appearance[†]	Overall Acceptability[†]
HSC	6.9 ± 0.8	6.9 ± 0.7	7.0 ± 0.7	7.5 ± 0.5	7.3 ± 0.7
IETFSC	7.1 ± 0.6	8.1 ± 0.7[a]	7.2 ± 0.8	7.4 ± 1.0	8.2 ± 0.8[a]

[a]Significantly different from HSB (control) (P < 0.05)
[†]Mean ± SD scores on 9-point hedonic scale
Total panelists, n = 10

Chapter 3 - Conclusion

Physical Effects

Unsaturated fats can be converted to saturated fats via a process called hydrogenation. Although the hydrogenation process is responsible for a majority of the *trans* fats found in food products, this process can be altered in various ways resulting in a decrease in *trans* fatty acid production. A popular technique used to decrease or eliminate the levels of *trans* fats in traditionally hydrogenated shortening is the process of interesterification. This process allows manufacturers to produce customized fats for various food applications.

- Cookies made with interesterified shortening tended to be wider and had more spread when compared to cookies made with traditionally hydrogenated shortening although sensory panelists indicated no statistically significant differences between the two cookie samples.
- Biscuits made with interesterified shortening had larger diameters, shorter heights, and greater spread than those made with traditionally hydrogenated shortening but were found acceptable by a sensory panel.
- Ahmadi and Marangoni's study (2009) revealed the potential of using interesterified shortenings in cookie dough applications and the study by Handa et al. (2010) supported the aforementioned research and extended the use of interesterified shortenings to biscuit dough applications.

Finally, plant breeding techniques can be utilized to obtain oils with desired characteristics. Genetic modifications can be achieved either through conventional or molecular plant breeding. Soybean cultivars are commonly altered to yield oils with desirable flavors and stabilities while containing lower *trans* fat levels than their wild type counterparts.

- The study by Gerde et al. (2007) focused on unique soybean cultivars bred to contain significantly lower levels of linolenic acid than common commercial varieties.
- The results from this study indicated that the oils with the lowest concentrations of linolenic acid had the highest stability.
- Both the low linolenic and the Asoyia oils were shown to have sufficient heat and oxidative stability allowing them to be suitable substitutes for traditional hydrogenated oils containing *trans* fats.

Nutritional Effects

Over twelve million people die each year from cardiovascular disease which is currently the leading cause of death in both the United States and Europe. Epidemiological studies have shown a causal relationship between the consumption of saturated fats and the presence of high cholesterol and CHD.

- The Harvard School of Public Health study confirmed the link between *trans* fatty acid concentrations in the blood and risk of CHD.
- The Mensink and Katan study indicated that *trans* fatty acid consumption resulted in increased LDL cholesterol and decreased HDL cholesterol.
- Finally Hu et al. (2007) demonstrated that replacing 2% of a person's typical calorie intake from *trans* fatty acids with *cis*-unsaturated fats yielded a 53% decrease in CHD incidence rates.

Sensory Effects

Even though a *trans*-free oil or shortening may have the desired functionality needed for a particular frying or baking application, consumers may not accept a reformulated product.

- The Bordi doughnut frying study (2010) demonstrated that commercially available *trans*-free canola and palm shortenings were acceptable alternatives to traditional *trans* containing vegetable oils used in bakery frying applications.
- Hack et al. (2008) showed that when presented with French fries that had been fried in commercially available *trans* fat-free frying oils such as Mazola® ZT, FryMax®, and Pour'n Fry®, panelists indicated higher liking scores than for traditional hydrogenated oils.
- A similar French fry study by Gerde et al. (2007) indicated that the use of Asoyia or low-linolenic acid oils resulted in more favorable panelist scores in terms of off-flavors related to oxidation than the *trans* containing oil. These oils would be beneficial to extend fry life and reduce cost in frying operations.
- The interesterified shortening cookie study by Ahmadi and Marangoni (2009) demonstrated that an untrained panel could not discern between the cookies prepared with IE shortening and traditionally hydrogenated shortening.
- In a similar cookie study by Bordi (2007), panelists were presented with *trans* containing and *trans*-free sugar cookies and asked to evaluate the samples for sweetness, appearance, texture, taste, and overall liking. Panelists rated the *trans*-containing sugar cookie higher in terms of appearance while the *trans* free cookie received significantly higher ratings in terms of sweetness. No significant differences were indicated for taste, texture, and overall liking.

- Finally, the interesterified shortening biscuit study by Handa et al. (2010) indicated that panelists found the *trans*-free biscuits more desirable in terms of flavor and overall acceptability while no differences were found in terms of color, texture, and appearance.

For frying applications the research has indicated that specially blended oils such as *trans*-free palm and *trans*-free canola, commercially available *trans*-free oils such as Mazola® ZT, FryMax®, and Pour'n Fry®, and less commonly used low- and no-*trans* oils such as cottonseed and Asoyia oils are healthy and proven alternatives to conventional frying oils. In the baking industry, research has shown that both emulsified and interesterified liquid shortenings provide the same functionality as their counterparts that contain *trans* fats while also being acceptable to consumers.

Because *trans* fats are so detrimental to human health, it is imperative that we convert to these alternatives for frying and baking. With these formulation changes, the overall health of Americans will improve and we should see declines in coronary heart disease, hypertension, and allergic conditions. One concern is that while there are many options when it comes to *trans* fat-free shortenings and oils, many of these alternatives have significantly high levels of saturated fats which are also detrimental to our health (Semma 2002). Future research should focus on functional fats and oils that are both *trans*-free and low in saturated fats. I believe that plant breeding will be instrumental in developing new, healthier fats in the future.

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