THE CHEMICAL AND FUNCTIONAL PROPERTIES OF COTTONSEED OIL AS A DEEP-FAT FRYING MEDIUM

by

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ABSTRACT

The purpose of this research study was to determine if unhydrogenated cottonseed oil was suitable for the deep-fat frying process and to determine the nutritional characteristics of the cottonseed oil and the french fries cooked in the oil. Cottonseed oil, partially hydrogenated canola oil and partially hydrogenated soybean oil were subjected to a temperature of 177°C for 8 hours per day and 6 batches of french fries were fried per day for 5 consecutive days. French fries were weighed prior to frying, cooked for 5 minutes, allowed to drain, and reweighed. Oil was not replenished, filtered once per day, and weighed daily before and after frying. Both the oil and the french fries were evaluated to determine color, fatty acid profiles, trans fatty acids, crude fat, and moisture. The french fries were analyzed for total polar materials and the oil was analyzed for iodine values, peroxide values, p-anisidine values, free fatty acids and totox values.

No significant differences were found among oil types for loss of oil during cooking, weight of french fries before and after cooking, color, moisture, and crude fat. Iodine values for all three oil types were significantly different. Both canola oil and soybean oil had significantly lower iodine values than cottonseed oil due to being partially hydrogenated. Free fatty acid values were not significantly different for the three oil types. Cottonseed oil, regardless of days of frying, had higher peroxide values, p-anisidine values and totox values compare to canola oil and soybean oil, indicating an increased presence of primary and secondary oxidation products. However, as days of frying increased, values for all three oils trended closer together. There were no significant differences in total

polar materials for french fries cooked in the three oils. Fatty acid profiles for both the french fries and the oil remained relatively stable as frying days increased. The analytical tests indicated that none of the three oil types reached a highly deteriorated state. Cottonseed oil was significantly lower in trans fatty acids than the other oils, as were the french fries prepared in the oil. Cottonseed oil appeared to be as stable as canola oil and soybean oil, however the oils would need to be stressed to a much greater degree to confirm this. In regard to dietary components associated with potential negative health effects, french fries cooked in cottonseed oil were slightly higher in saturated fatty acids, but markedly lower in trans fatty acids than those cooked in canola oil and soybean oil.

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CHAPTER I

INTRODUCTION

Vegetable sources account for approximately 85% of the fats and oils consumed in the U.S. today (O'Brien 1998). Many vegetable oils compete in the American market including cottonseed oil. Cottonseed oil was the preferred vegetable oil in the U.S. in the 1950's, until soybean oil overtook the market due to lower production costs. Consumers expect that food service establishments and processors will provide them with healthy food choices in addition to quality flavor, mouthfeel, and texture. Despite the negative health effects, deep-fat fried snack foods remain very popular among consumers. The unique sensory qualities found in foods that are deep-fat fried can not be duplicated by any other cooking method. In particular, french fries remain a very popular food item in the American diet. On average, each person in the United States consumes approximately 13.6 kg (30 pounds) of french fries every year (Ebersole 2002). Therefore, the food-service industry has the difficult task of providing the popular french fry in the healthiest form possible. This task may appear to be an oxymoron, however, choosing the right oil can be the key to providing a tasty and healthier french fry at a low cost.

Cottonseed oil could be a superior choice to meeting the above requirements. One reason is that cottonseed oil enhances the flavor of foods cooked in it (Jones and King 1993). It is well established that cottonseed oil produces the most flavorful potato chip on the market. Another reason is that it is not necessary to hydrogenate cottonseed oil to

increase its stability. Sheaffer (1998) compared the frying performance of cottonseed oil and canola oil using french fries. It was found that unhydrogenated cottonseed oil had similar stability characteristics as compared to hydrogenated canola oil. Because it is not necessary to hydrogenate cottonseed oil, it results in a fried food product with a low concentration of trans fatty acids. Trans fatty acids have been implicated in causing heart disease. It has also been postulated (Sheaffer 1998) that foods fried in cottonseed oil absorb less fat than foods fried in other oils.

This research will build upon previous studies by evaluating the frying performance of cottonseed oil using french fries and comparing it to partially hydrogenated canola oil and partially hydrogenated soybean oil. Research conditions will simulate the food service setting as close as possible in order to produce results that can be applied commercially. The chemical characteristics of unhydrogenated cottonseed oil will be compared to that of hydrogenated canola and hydrogenated soybean oil throughout the study period to assess the nutritional value and stability characteristics of the oils. The amount of oil loss will also be determined by physical measurement in addition to compositional evaluation. The goal of this research will be to provide scientifically valid data in order to determine if there are benefits to using cottonseed oil as a substitute for the partially hydrogenated oils commonly used as a deep-fat frying medium by the restaurant industry.

Objective

The objective of this study is to provide scientifically valid data on the physical, chemical and stability characteristics of cottonseed oil as a deep-fat frying medium for use by the restaurant industry.

Statement of problem and significance

To determine the attributes of cottonseed oil as a deep-fat frying medium for use in the food service industry.

Hypotheses

The two hypotheses tested are stated below:

1. Cottonseed oil as a frying medium has stability characteristics that differ from hydrogenated canola oil and/or hydrogenated soybean oil.
2. The composition of french fries fried in cottonseed oil differs from french fries fried in hydrogenated canola oil and/or hydrogenated soybean oil.

CHAPTER II

REVIEW OF LITERATURE

History of cottonseed oil

Prior to the civil war, surplus cottonseed was only utilized as feed for cattle or as fertilizer on depleted cotton and corn fields (Wrenn 1995). Rotting cottonseed became such a problem in the south that several states passed laws to regulate its disposal. During the 20th century, this supposedly "worthless" cottonseed became the second most precious cash crop in the South. This was due to the manufacture of cottonseed into marketable commodities.

Salunkhe et al. (1992) describe the vast utilization of cottonseed. Cottonseed hulls are used as roughage in livestock feeds and are used for a variety of other purposes such as fuel for oil mills, insulation material and soil conditioner. Cottonseed meal is used in the textile industry and is also used as an adhesive. Cottonseed proteins are used as a nutritious protein source for human consumption. The manufacture of salad and cooking oils, shortenings and margarine comprise almost the entire market for cottonseed oil. The remainder of the oil is used in the manufacture of non-edible items such as soap, and it is also used to pack fish and cured meats.

Cottonseed oil was used to produce the first hydrogenated-all vegetable shortening product for the retail trade (Wrenn 1995). Crystallized cottonseed oil (Crisco®), was introduced in the early 1900s by Proctor & Gamble who had a patent on the hydrogenation process (Wrenn 1995). Once hydrogenation became accessible to other

manufactures, less expensive, lower grade oils were able to compete in the market. Nationally, cottonseed oil competes with soybean oil, corn oil, peanut oil, sunflower oil, safflower oil, and some animal fats (NCPA 1990). Cottonseed oil must compete internationally with coconut oil from Southeast Asia, palm oil from Malaysia, African peanut oil, olive oil from the Mediterranean basin, European sunflower oil and Canadian rapeseed oil (NCPA 1990). The dominant position of cottonseed oil in the early 1900's started to decline secondary to the advent of improved processing methods (hydrogenation and deodorization) that greatly improved not only the quality of cottonseed oil but other oils as well. In addition, the increased use of cottonseed for cattle feed has decreased cottonseed oil production (Jones and King 1993).

Cottonseed oil remains fifth in world production due to the competition from these other oils (Jones and King 1993). Cottonseed oil is difficult to market because its supply relies on cotton production, which can be variable according to climate conditions. This is a disadvantage to customers who rely on a stable supply of oil to support their finished products (Jones and King 1993). During the period from the 1940's to the 1960's, the encouragement of soybean production to increase the supply of protein caused cottonseed oil prices to be placed at a disadvantage (Smith 1962). According to the USDA (1988) cottonseed oil is perceived as an expensive oil due to its exceptional performance characteristics in food applications, however, it can be priced lower than soybean and other oils. Typically, oil prices around the world are closely related and remain competitive with each other (NCPA 1990).

Processing of cottonseed

Jones and King (1993) describe the processing of cottonseed oil:

1. Cottonseed is cleaned by a variety of screening methods.
2. Linter fibers are removed mechanically using cottonseed delinter machines. Lint must be removed in order to improve the yield of the oil. Lint comprises approximately 8.6% of the seed.
3. Hulls are removed from the seed to improve the protein quality of the meal produced and prevent oil sorption by the hulls. The hulls are removed by either a bar huller or seed decorticator.
4. Reduction involves flaking or reducing the size of the meat once the hulls are removed in order to simplify oil removal. Seeds can either be flaked by passing through two side-by-side rollers or more commonly, by passing through a series of five crushing rollers.
5. The seeds are cooked in steam-jacketed kettles in two separate phases. The first phase utilizes a temperature of 88°C while the second phase utilizes a temperature range of 110 °C-132 °C. The final moisture content of the seeds is between 3-6%, depending on which extraction method is used. Cooking breaks down cell walls which allows the oil to escape, reduces oil viscosity, controls moisture content, inactivates enzymes, kills microorganisms, detoxifies gossypol and binds phosphatides (Ward 1976).
6. Three methods are used in the industry to extract oil: screw press, solvent method, or a combination of the two. The solvent method, which uses hexane, is the most common.

Refining of cottonseed oil

To be utilized as a human food source raw cottonseed oil must be refined to remove impurities, which ensures desirable flavor, color and stability characteristics. Refining is the most important step in the purification process of oil and involves removing the nonglyceride components such as phospholipids, color, and trace metals and free fatty acids (Jones and King 1993). The process mixes alkali and oil to form soaps. The non-glyceride components contained in the soap are then removed by using centrifugation and hot water washings (NCPA 1996). Bleaching furthers the purification process which involves the removal of color bodies, trace metals, and soaps by using bleaching clays that absorb the impurities (Jones and King 1993).

Deodorization is an essential step in the refining process. The process removes volatile compounds that can produce off-odors and off-flavors, leaving the oil with a 0.01-0.03% free fatty acid content and a zero peroxide value (Gavin 1978). This process was perfected by David Wesson in the twentieth century who exposed the oil to superheated steam in a vacuum (Wrenn 1995). Along with free fatty acids, aldehydes, ketones, alcohols and hydrocarbons associated with undesirable flavors and odors produced by autoxidation are removed (Jones and King 1993). Cottonseed oil can be deodorized at lower temperatures, resulting in less loss of tocopherols that are natural antioxidants that help retard oxidation (NCPA 1996).

Manufacturing of cottonseed oil

Depending on the intended use of the oil, cottonseed oil can be winterized or hydrogenated. Cottonseed oil must be winterized before being marketed as a salad oil to remove the cloudiness caused by stearine (Wrenn 1995). Stearine solidifies at refrigerator temperatures due to its saturated fat content. To produce a clear cottonseed oil, the oil is cooled until the stearine precipitates.

Hydrogenation of oil increases the stability. This allows it to withstand high and prolonged temperature abuse such as that which occurs in deep-fat frying. Hydrogenation is the process by which hydrogen is added to unsaturated double bonds in a fatty acid chain by reacting fatty acids with hydrogen gas in the presence of a catalyst. Hydrogenation was developed in the early 1900s to produce a less costly solid vegetable oil product to replace lard (American Society of Clinical Nutrition 1995). The purpose of hydrogenation is to reduce the potential for oxidative damage, increase the stability of the oil and to solidify the oil (Nawar 1996). The process increases the melting point of oils and helps retard oxidation and flavor deterioration (Salunkhe et al. 1992). Hydrogenation not only adds hydrogen to the double bond, it also results in migration of double bonds and reconfiguration of some of the cis double bonds into trans double bonds. Trans fatty acids are so named because the hydrogen atoms on the carbon atoms involved in the double bond are on opposite sides of the carbon chain, whereas in naturally occurring unsaturated fatty acids (cis isomers), the hydrogen atoms on the carbon atoms involved in the double bond are on the same side of the carbon chain (Ascherio and others 1999).

Oils that require hydrogenation to increase stability are usually high in polyunsaturated and monounsaturated fatty acids. Polyunsaturated fatty acids such as linoleic and linolenic acids that have a tendency to oxidize and become rancid are reduced during hydrogenation, which prolongs storage time (Ascherio et al. 1999). Oils that are higher in saturated fats are more stable. Oil must meet a certain quality standard in order for hydrogenation to be effective. The requirements are that the oil contain <0.1% free fatty acids, <1.5 ppm soap and <0.1% moisture (Puri 1980). In addition, it should have a low color and a peroxide value <10 meq/kg because polar pigments and oxidized ions can act as catalyst poisons (Puri 1980).

Frying

Frying is one of the oldest cooking methods (Varela et al. 1988). Deep-fat frying is commonly used by the food service industry. In the United States, the fried food industry increased by approximately 88% between the years of 1979 and 1988 (Tettweiler 1991), in spite of recommendations from organizations such as the American Heart Association to limit intake of fried food

Deep-fat frying is the complete immersion of a product in heated oil. Many complex changes occur in fats and oil during the frying process. Heat is transferred to the food product by conduction and convection. Conductive heat transfer occurs within the food under unsteady state conditions (Singh 1995). Convective heat transfer occurs between the food and the surrounding oil (Singh 1995). Farkus (1994) proposed that the frying process occurs in four different phases:

1. The characteristic of the initial heating stage is that the surface of the product immersed in the oil reaches the same temperature as the boiling point of the liquid. The mode of heat transfer is convection and this last only a few seconds with no vaporization occurring from the surface of the food.
2. The surface boiling stage is initiated by the vaporization process. Forced convection is the mode of heat transfer due to increased turbulence in the surrounding oil. The crust begins to form on the surface of the food during this stage.
3. The falling rate is the stage that when the internal temperature of the food reaches the boiling point and the most moisture leaves the internal region of the food. At this point, the starch content of the internal region of the food begins to gelatinize and cook. More moisture is lost and the crust layer continues to increase in thickness.
4. The bubble end-point is the final stage in the frying process. The moisture loss diminishes, and no more bubbles are seen escaping from the surface of the product. The crust layer continues to thicken.

Degradation

The more oxidatively stable oil is, the longer it can withstand the abuse it suffers during the deep-fat frying process. Industry and food service operators expect highly stable oil to reduce operation costs. The stability of the oil is directly related to how often it must be replenished and/or completely changed out. In order to control the quality of the end product and the life of the oil, this degradation process, or loss of stability, must be understood.

Oil degradation occurs simply through the aging process and use. The degradation process of cooking oil is a five-phase process described by Blumenthal (1988) (Figure 1).

1. Break-in oil - white product; raw, ungelatinized starch at center of the fry; no cooked odors; no crisping of the surface; little oil pickup by the food.
2. Fresh oil - slight browning at the edges of the fry; partially cooked centers; crisping of the surface; slightly more oil absorption.
3. Optimum oil - golden-brown color; crisp, rigid surfaces; delicious potato and oil odors; fully cooked centers (rigid, ringing gel); optimal oil absorption.
4. Degrading oil - darkened and/or spotty surfaces; excess oil pickup; product moving toward limpness; casehardened surfaces.
5. Runaway oil - dark, case-hardened surfaces; excessively oily product; surfaces collapsing inward; centers not fully cooked; off-odor and off-flavors (burned).

The longer an oil can stay in the optimum phase, the more useful and cost-effective it is for commercial food service.

Visual degradation of the oil includes decreased smoke point, increased viscosity, darkened color, and increased foaming (Gere 1983; Perkins 1967; Rock and Roth 1967; Tangel et al. 1977). White smoke over frying oils is normal and is mostly steam. Blue to gray smoke contains organics co-distilling with steam and can indicate that the oil needs to be discarded. However, this condition cannot be used for quantification.

Viscosity is the ability of oil to resist flow. As the temperature increases, viscosity decreases. Saturation and larger molecules, such as long chain fatty acids or polymerized

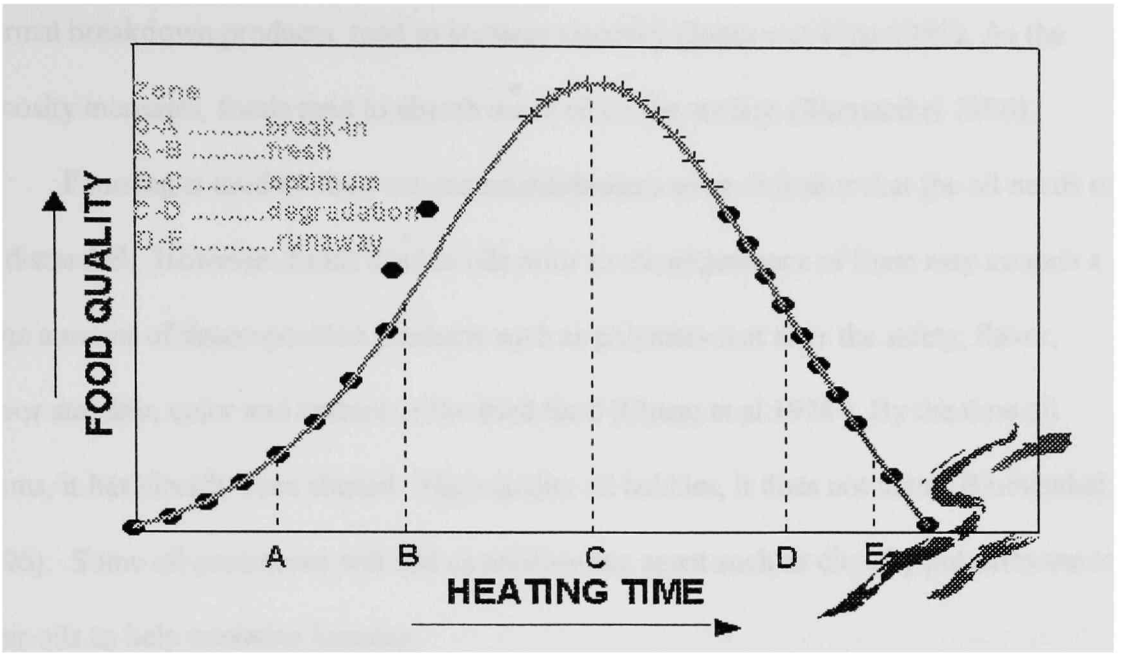

Figure 1. Frying oil/food quality curve (Blumenthal 1988).

thermal breakdown products, tend to increase viscosity (Jones and King 1993). As the viscosity increases, foods tend to absorb more oil on the surface (Blumenthal 1996).

Foaming is used by food service establishments as an indicator that the oil needs to be discarded. However, foods fried in oils prior to the appearance of foam may contain a large amount of decomposition products such as polymers that alter the safety, flavor, flavor stability, color and texture of the fried food (Chang et al 1978). By the time oil foams, it has already been abused. High quality oil bubbles, it does not foam (Blumenthal 1996). Some oil processors will add an antifoaming agent such as dimethylpolysiloxane to their oils to help minimize foaming.

The color of oil is often used as an indicator of quality, however, fresh (unused) oils vary in color. Processing techniques and pigments such as carotene are responsible for the differences in color between various fresh (unused) oils (Jones and King 1993). Oils darken in color as they are heated and used for frying. This is due to the presence of polymers and oil-soluble products from the fried food (Blumenthal 1996). Other factors that influence oil color include the type and amount of food being fried, batch of the oil, completeness of filtration, temperature, and the type of fryer (Takeoka et al. 1997). Since there are so many factors involved in the determination of oil color, it should only be used as a marker, not as the overall determinant of oil quality.

Visual analysis of the color of oil is commonly used, but it is highly variable. Methods for expressing color numerically were developed by the CIE (Commission Internationale d'Eclairage), an international organization concerned with light and color (Minolta 1993). The two most commonly used methods to express color numerically are

the Yxy color space, devised in 1931 by CIE, and the L*a*b* color space, devised in 1976 to provide more consistent color differences in relation to visual differences. The L*a*b* color values of liquid oil samples can be quantified using ultraviolet-visible sphectophotometers (Maes et al. 1997). L* indicates lightness, and a* and b* indicate chromaticity. The a* value is positive in the red direction and negative in the green direction while the *b value is positive in the yellow direction and negative in the blue direction (Minolta 1993). An L* value of 100 is equal to white, and the value of 0 is equal to black. The a* value represents the color spectrum of red to green. The redness of a sample is represented with a positive value of 100, while the greenness of a sample is represented with a value of −100. The b* value represents the color spectrum of yellow to blue. The yellowness of a sample is represented with a value of positive 100, while the blueness of a sample is represented with a value of −100 (Minolta 1993). These values can then be converted into everyday language represented by hue, lightness, and saturation (chroma). Hue is the classification of red, yellow, blue, etc.; lightness represents bright and dark colors; saturation describes whether a color is dull or vivid (Minolta 1993).

Chemical degradation of lipids

Chemical degradation can occur rapidly during the deep-fat frying process and includes hydrolysis (lipolysis), oxidation, and polymerization (Clark and Serbia 1991). Lipolysis involves cleavage of fatty acid chains from the glycerol molecule (hydrolysis), resulting in release of free fatty acids. Free fatty acids can be responsible for off-odor and off-flavor development. Lipolysis can occur enzymatically due to the reaction of lipids

with enzymes, or non-enymatically due to the presence of heat and water. Lipolysis is a major problem in the deep-fat frying of foods and is secondary to the large amounts of water introduced from the food while frying and the high temperatures used (Fennema 1985). Prior to harvest, the oilseed can contain large amounts of free fatty acids, however, most of these are removed in the refining process. Free fatty acids that develop during frying can cause problems such as decreased smoke point and surface tension of the oil, thus reducing the quality of the fried food (Fennema 1985).

Lipid oxidation is the primary chemical degradation process and can produce both satisfactory and unsatisfactory flavor compounds. Excessive lipid oxidation renders edible oils and fat-containing foods unacceptable, reduces shelf life, and decreases the nutritional quality of the food (Fennema 1985). However, a small amount of oxidation can actually enhance the fried flavor. Autoxidation is the predominant oxidative reaction and is described by Ho et al. (1996).

Autoxidation is a chain reaction initiated by a free radical mechanism. The initiation reaction usually occurs not by the reaction of unsaturated fatty acids with oxygen, but by the decomposition of hydroperoxide. This occurs in the presence of catalysts such as metal, heat or exposure to light, or by singlet oxygen.

Propagation is the next step in the chain reaction after free radical formation. Hydrogen radicals are removed from the double bond position and oxygen attacks to form peroxy radicals. Hydroperoxides are then formed from hydrogen from other substrate groups, these substrate groups go on to react with oxygen, and the chain reaction continues.

The process is terminated by the interaction between two free radicals. Many decomposition compounds are formed and can be classified as volatile products – hydrocarbons, aldehydes, ketones, furans, carboxylic acids; or nonvolatile products – polar and nonpolar cyclic monomers, non-cyclic monomers, dimers, trimers, and higher molecular weight compounds (White 1991).

"Oxidative rancidity" is the term used to describe fats and oils that have developed objectional flavors and odors due to autoxidation. The degree of unsaturation, the presence of antioxidants, and light affect the rate of oxidation. Hydrogenation is one method used to retard oxidation by increasing the saturated fatty acid content of the oil. Many oil processors add chelating agents to their oils, such as citric acid, to retard oxidation caused by heavy metals (Institute of Shortening and Edible Oils 1999). Cottonseed oil naturally contains tocopherol, which is an antioxidant that helps retard oxidation (Salunkhe et al. 1992). Unprocessed cottonseed oil contains approximately 1000 ppm of tocopherols, however, up to one third can be lost during refining (Jones and King 1993). Various researchers have found levels of tocopherol in commercially refined cottonseed oil to be between 633 ppm to 950 ppm (Sherwin 1976; List and Friedrich 1989; Slover et al. 1969). Some oil processors will add tertiary butylhydroquinone (TBHQ) as an antioxidant. TBHQ gives oxidative stability to polyunsaturated oils without creating problems of color or flavor stability (Fennema 1985). Processors also protect fats and oils from light to prevent oxidation and increase shelf life.

Filtration also helps maintain the quality of oil. Reduced smoke point and increased fat deterioration, especially an increase in free fatty acids, are associated with food

particles present in the frying medium (Jones and King 1993). There are a variety of fryers on the market, and thus vary in size, heating method, and cooking method. According to Jacobson (1991) the most important part of the frying equipment is the filtration system. The type and kind of filter influences the removal of "cracklings" which can ruin the appearance of the fried food, darken the oil, and impose off-flavors. Use of filtering powder polishes and neutralizes part of the free fatty acids (Jacobson 1991). Filtering powder can be used to aid the filtering process and to improve the quality of the oil. Filtering powder works by building up on the filter paper which traps more food debri, improves the color of oil, and improves the stability of oil by reducing the amounts of free fatty acids and total polar materials (Jones and King 1993). However, small amounts of the soaps that form remain in the hot frying oil after filtration and can cause darkening and undesirable flavor changes in the fat and products fried in the fat (Jacobson 1991).

Morton (1977) explained the polymerization process. It involves the formation of new carbon-carbon linkages in the absence of oxygen. Cyclic fatty acids are produced if the bonds are formed within one fatty acid. Development of bonds between two fatty acids results in dimeric acids, either within one triglyceride molecule or between two molecules. Formation of additional cross-links between these molecules produces polymers with high molecular weight. Oils and fats form polymers when subjected to extreme conditions of temperature and time, and occur in insignificant amounts under normal cooking conditions (Institute of Shortening and Edible Oils 1999).

Oil uptake

Americans are consuming large amounts of fats in the form of fried foods. Some fried foods contain excessive amounts of fat. In some cases it can reach more than 45% of the total product (Saguy and Pinthus 1995). Industries are hard pressed to provide quality fried foods which contain a lower amount of fat. The amount of oil uptake a food item possesses can greatly influence the fat content of that particular food. In today's health conscious environment, reducing the fat content of a product should greatly enhance its acceptance. Reduced content of fat in the finished product is not the only reason to reduce oil uptake. Studies questioning the safety of heated fats and oils are abundant in the scientific literature (Clark and Serbia 1991). Oil extracted from the food contains more polymers than the oil left in the fryer (Pokorny 1980). Excessive cooking conditions can produce toxic compounds in fats and oils, however unacceptable sensory qualities occur before the oil reaches this level of degradation (Clark and Serbia 1991).

Pinthus and others (1993) describe the factors reported to affect oil uptake. These include oil quality, product and oil temperature, frying duration, the particular foods' shape, composition (e.g., solids, moisture, fat, protein), and porosity, pre-frying treatments (e.g., blanching, drying), coating, surface roughness and others. To ensure that oil uptake is related to the nature of the oil product used in frying food, the factors listed above need to be strictly controlled.

It has been well documented that oil composition and quality influence oil uptake (Abdel-Aal and Karara 1986; Blumenthal 1987, 1991; Pokorny 1980). When an oil interacts with the food being fried, surfactants are formed which affect oil quality (Stier

and Blumenthal 1990, 1993). Surfactants affect fat absorption and heat transfer at the oil-food interface by reducing the surface tension of the oil (Saguy and Pinthus 1995). However, fresh oils form very little surfactants, while the majority of surfactants are formed in degraded oils (Blumenthal 1991).

The type of product being fried affects oil uptake. For example, potatoes are known to absorb more oil than meat (Min and Smouse 1989). The most notable change in the french fry during the frying process is a large amount of moisture loss and an increase in the fat content (Table 1). Since french fries are one of the top selling menu items at every menu price level in the restaurant industry (Anon 1982 a, b), if restaurants serving them provide the lowest fat product possible it will have a major impact on fat consumption by consumers.

Gamble et al. (1987) suggested that there is a linear relationship between moisture loss and oil uptake throughout the deep-fat frying process. However, other research has found no relationship between these two variables (Dupont et al. 1992). French fries that are pre-dried absorb less oil, however, this type of treatment may decrease sensory quality (Gupta et al. 2000). Freezing french fries prior to frying will also decrease oil uptake (Weaver et al. 1975).

Lab analyses

More than 400 different chemical compounds have been discovered in degraded, heated oil (Gere 1982). There are many tests available to determine oil composition throughout the various stages of decline. Sensory evaluation will remain the best

Table 1. Changes in the composition during frying of french fries[1]

Component	Character of Changes
Water	Substantial losses
Fat	Pronounced increase (original fat is negligible
Reducing sugars; sucrose	Maillard reactions
Flavor	Volatiles from Maillard reactions
	Interactions with frying oil
Starch	Gelatinization, dextrinization
Amino acids	Formation of heterocyclic flavor substances, mutagens
Proteins	Denaturation
Minerals	Slight decrease

[1]Pokorny 1999

approach for determining the flavor and odor of heated oils. However, determining oil degradation by objective methodology is also very helpful and can be successfully correlated with sensory information.

Total polar materials

Measurement of Total Polar Materials (TPM) is useful in estimating heat abuse in frying oils. Evaluating total polar materials has recently been characterized as one of the best indicators of heated oil quality (Blumenthal 1991). TPM includes all nontriacylglycerols such as free fatty acids, mono- and diacylglycerols, glycerol, and polymers (Tan and Man 1999). TPM are those materials that are left on the silica gel column after first elution when heated oil is tested using AOCS Official Method 20-91 (AOCS 1998). Bulk fresh oil from the factory contains approximately 96% triglycerides (Blumenthal 1991). As an oil is used, TPM accumulates in the oil while triglycerides decrease in direct proportion (Blumenthal 1991). At the point it is discarded, or even before that, an oil used at a fast food chain contained about 25% TPM, resulting in only about 75% triglycerides (Blumenthal 1991). The degradation materials which are contained within the polar fraction account for the cooking and eating qualities of the oil, and may be toxic (Blumenthal 1991).

Free fatty acids

Free fatty acids (FFA) (AOCS 1998, Ca 5qa-40) measures fatty acid changes that occur in oils during deep-fat frying. Free fatty acids are pro-oxidants and contribute to the

decreased shelf life of oil (Frega and others 1999). In the initial stage of cooking, free fatty acids are produced by oxidative breakdown, but in later stages, hydrolysis of the fat caused by the presence of moisture in the food being fried causes the increase in free fatty acids (Blumenthal 1996). In most deep fat frying operations, the presence of FFA produced by hydrolysis is too small to affect the quality of the food, while the FFA formed by oxidation will adversely affect the product (Tyagi and Vasishtha 1996). Generation of up to 2% FFA from hydrolysis in oils that contain minute amounts of lauric acid, such as soybean and cottonseed oil, has no adverse effect on the odor or the flavor of foods (Tyagi and Vasishtha 1996). Oils high in lauric acid will produce a soapy flavor at ca. 0.5% FFA content (Tyagi and Vasishtha 1996). When significant amounts of free fatty acids are present in the oil, smoking becomes excessive and the oil must be discarded (Blumenthal 1996). Detection of increases in FFA by titration is a poor measure of oil quality because it does not differentiate between acids formed by oxidation and those formed by hydrolysis. Free fatty acid levels are 0.05% in fresh refined, bleached, and deodorized oils (Jones and King 1993).

Iodine value

Iodine value (AOCS 1998, Cd 1-25) is a simple test used in the oil industry which has a direct relationship to the deterioration of the quality of the oil. For the iodine value to be of any reasonable estimate, there must be an unheated reference sample in order to determine the change in the values (Waltking et al. 1975). The iodine value indicates the number of unsaturated fatty acids (Jones and King 1993). The iodine value is a good

estimate of lipid stability because fats with larger proportions of saturated fatty acids are less likely to undergo autoxidation (Jones and King 1993). The PUFA content in oils will undergo a steady increase in saturation as frying time increases.

Peroxide value

Peroxide value (AOCS 1998, Cd 8b-90) is a test that measures primary oxidation in its early stage, however, it may not be a good measure of heat abuse in PUFA-rich oils. Hydroperoxides are the initial and primary products of lipid oxidation. They are transitory and are broken down by further reactions (Jackson 1981). Hydroperoxides can be quantitatively measured by determining the amount of iodine liberated by their reaction with potassium iodide (Blumenthal 1996). In PUFA-rich oils, peroxides are formed through the oxidation of free radicals obtained from abstraction of protons from methylene-interrupted fatty molecules (Tyagi and Vasishtha 1996). PUFA-rich oils decompose much faster than oils with less triene by means of labile hydrogen, obtained from the active methylene group of another molecule, which causes free radical polymerization (Tyagi and Vasishtha 1996). Tyagi and Vasishtha (1996) concluded that oils containing trans isomers could inhibit free radical polymerization by restricting the decomposition of peroxides. Peroxides quickly breakdown to non-peroxide compounds, making their correlation with flavor variable (Jackson 1981). For a product to have acceptable shelf life, the peroxide value should be less than 1.0 meq/kg fat at the point of use (Blumenthal 1996).

Totox number

Totox number (AOCS 1998, Cd 18-90) is a test that correlates well with oxidation and flavor in oils. The totox value is the anisidine value + 2 times the peroxide value. Using this combination of tests results in higher correlations with flavor than using the p-anisidine value alone (Jackson 1981). The p-anisidine value is primarily a measure of alpha-beta-unsaturated aldehydes (Jackson 1981). Aldehydes are secondary lipid oxidation products and account for 50% of the volatiles produced during oxidation (Tompkins and Perkins 1999). In particular, trans -2,trans –4 decadianal (a precursor of linoleic acid) is associated with fried food flavor, and its correlation with p-anisidine value is highly significant (Tompkins and Perkins 1999).

Fatty acid profiles

It is important to determine fatty acid profiles in both fresh and used oil because the fatty acid composition in oils changes during deep-fat frying. Thompson and Aust (1983) and Miller and White (1988) evaluated changes in the fatty acid composition of frying oils after 40-100 hours of frying. Both studies found that linoleic and linolenic acid levels dropped, while amounts of saturated fatty acids increased. The decrease in unsaturation can be attributed to the destruction of double bonds by oxidation, scission, and polymerization (Tyagi and Vasishtha 1996). The amounts and types of fatty acids present in oil contribute to its functional properties. The fatty acid profiles of commonly used oils are listed in Table 2.

Table 2. Characteristics of cottonseed oil, canola oil, and soybean oil[1].

Parameters	Cottonseed oil	Canola oil	Soybean oil
	Unhydrogenated	Unhydrogenated	Unhydrogenated
Free fatty acids (as oleic acid)	Not more than 0.05%	Not more than 0.05%	Not more than 0.1%
Iodine value	99-119	110-126	120-143
Peroxide value	Not more than 1 meq/kg	Not more than 1 meq/kg	Not more than 1 meq/kg
p-Anisidine value[2]	<10	<10	<10
Linolenic acid	Not more than 2.1%	Not more than 14%	Not more than1.5%
Water	Not more than 0.1%	Not more than 0.1%	Not more than 0.1%

[1]NCPA 1996
[2]Eskin et al. 1996

Composition of the oils

Cottonseed oil has been the preferred oil for frying potato chips in the southern U.S.A. (Weiss 1983). In 1995/1996, 497 million pounds of cottonseed oil in the form of shortening, margarine, salad and cooking oils were used in food (Institute of Shortening and Edible Oils 1999). Cottonseed oil contains higher proportions of saturated fatty acids (24.6%) as compared to soybean oil (14.7%) and canola oil (6.1%) (Salunkhe et al. 1992). However, the saturated fatty acid content reported for canola oil and soybean oil was obtained from the unhydrogenated oils.

Cottonseed oil contains 40-55% linoleic acid, 20-25% palmitic acid, 2-7% stearic acid, 18-30% oleic acid, and small amounts of myristic and arachidonic acids and approximately 0.5-2% cyclopropenoid acids (Salunkhe et al. 1992). Cottonseed oil contains virtually no linolenic acids, which considerably strengthens its stability for frying (NCPA 1996).

Canola oil was developed from rapeseed varieties (*Brassica napus and Brassica rapa*) and it must contain less than 2% erucic acid according to the Canola Council of Canada (Eskin et al. 1996). The rapeseed must undergo similar processing steps as those applied to other vegetable oils in order to produce an edible oil product.

Hydrogenation is commonly used to improve the melting behavior and oxidative stability of canola oil. One of the major problems encountered during the hydrogenation of canola oil is an increase in the amount of trans fatty acids. Canola oil contains a small amount of sulfur compounds (Eskin et al. 1996). These sulfur compounds poison the catalyst, which results in slightly higher trans fatty acid formations. Research is being

conducted to develop a true zero glucosinate (a compound that is hydrolyzed to isothiocyanates and other sulfur-containing compounds) oil, which is expected to eliminate the problem (Eskin et al. 1996).

Canola oil ranks third among the oilseed crops, behind soybean and palm oil in the production of edible oils (Salunkhe et al. 1992). In the years 1995/1996, 319 million pounds was used in food in the form of shortening, margarine, salad and cooking oil (Institute of Shortening and Edible Oils 1999). Canola oil is the least saturated oil on the market and has a naturally high content of linolenic acid content (11-12%) (Carr 1991). Plant breeders have been able to reduce the linolenic acid content to 2.1%, increase the linoleic acid from 20% to 27%, and increase the oleic acid content from 60 to 85% with the intent of producing a very stable oil (Eskin et al. 1996).

Soybean oil is the most widely produced oil in the U.S. and the world. In 1995/1996, 11,877 billion pounds of oil was used in food in the form of shortening, margarine, salad and cooking oil (Institute of Shortening and Edible Oils 1999). Because of its high linolenic acid content (6.8%), soybean oil must be hydrogenated to produce a stable oil used under frying conditions (Eskin and others 1996). In addition, linolenic acid is responsible for the oil's flavor and odor reversion. Light hydrogenation reduces the linolenic acid content to approximately 3% and flavor stability is improved (Ho et al. 1996). On average, unhydrogenated soybean oil contains 22.8% oleic, 50.8% linoleic, and 6.8% linolenic (Eskin et al. 1996). Table 3 summarizes the fatty acid composition of unhydrogenated cottonseed oil, canola oil and soybean oil.

Table 3. Typical fatty acid profile of cottonseed oil, canola oil and soybean oil[1]

Fatty Acid Composition (%)	Cottonseed Oil	Canola Oil	Soybean Oil
Myristic (14:0)	0.5-2.5	0.1	<0.5
Palmitic (16:0)	17-29	3.5	7-12
Stearic (18:0)	1-4	1.5	2-5.5
Oleic (18:1)	13-44	60.1	20-50
Linoleic (18:2)	33-58	20.1	35-60
Linolenic (18:3)	0.1-2.1	9.6	2-13

[1]Obtained from Bailey's Industrial Oil and Fat Products (Eskin et al., 1996)

Potatoes

Potatoes, mainly in the form of french fries, comprise half of the vegetables consumed by Americans (Gower 1992). There are four types of potatoes grown in the United States: Round White, Russet, Round Red and Long White (Empire State Potato Growers, Inc. 2000). Within this group, there are thousands of varieties that differ in days to maturity, color, shape, storage requirements, and purpose.

The four types of potatoes are classified into three categories of consistency based on texture. Round whites are considered all-purpose, Russet potatoes are mealy in texture and crumble when cooked, and Round Red and Long White are waxy which enables them to hold their shape (Empire State Potato Growers 2000). Russet potatoes provide the best texture and color for frying french fries. Russet potatoes with a specific gravity between 1.102 and 1.106 produce french fries of desirable textural qualities as characterized by mealiness, crispiness, and firmness (Jaswal 1991). The variety of the potato, growing conditions and location, storage temperature and methods of cooking all effect the texture (Jaswal 1991).

The color of a potato is determined by the amount of sugars present at the time of cooking. French fries should be light in color with no dark pigments. High concentrations of reducing sugars result in fried products that are dark in color and commercially unacceptable (Burton 1989). Glucose is the sugar most closely correlated to french fry color. A glucose concentration of less than 1.2 mg/g^{-1} and 1.60 mg/g^{-1} for Shepody and Russet Burbank, respectively, results in excellent fry quality (Pritchard and Adam 1994). Factors that affect color are basically the same factors that affect texture.

Russet Burbank is the dominant potato cultivar in North America where it constitutes over 70% of the planted acreage (National Potato Council 1994). It is utilized for tablestock and for processing into french fries and dehydrated products (Love et al. 1996).

Sensory properties

There are many objective analyses available to determine the decomposition products at various stages found in oil. However, there is not an instrument available that can replace the senses of a human being. Sensory evaluation is the scientific discipline for the qualitative and quantitative evaluation of foods (Warner 1996). It is the supreme method in assessing the quality and stability of fats, oils, and fat-containing foods (Warner 1996). There are two types of sensory panels-consumer and trained (analytical). Consumer panels anticipate direction of choice and in some cases, determine whether a product is preferred by some population (ASTM 1968). Trained sensory panelists provide a systematic application of the combined senses of taste and smell as analytical guides to the characteristic of the products tested (ASTM 1981). Trained sensory panels are more common in research. Trained sensory panels can either be difference or descriptive. As the name implies, difference panels determine whether a sample is different from another sample. Descriptive panels utilize highly trained judges that rate the product for quality or intensity based on precise scales, with reference standards that attempt to eliminate subjective analysis (Warner 1996). For sensory analysis to be even more effective, it can be coupled with chemical tests such as peroxide values and color analyses. Cottonseed oil

is known for its "nutty" flavor and is often used as the standard for which other oils are compared for pleasing aroma, flavor and performance (NCPA 1996). The sensory properties of oil are affected by frying time, temperature, oil type, whether the oil is fresh or has been replenished, frying equipment, type of food being fried, and any additives in the oil.

The initial flavor of oil is rather bland, and it takes some time to develop the fried flavor that consumers know and love. Therefore, the first stage of frying results in improved flavor, the flavor is maintained during the next stage, and in the last stage, the flavor becomes gradually less acceptable (Min and Smouse 1989). It is the job of the cook to maximize the second (or optimum stage as described above) of the frying process. The optimum phase can be prolonged by replenishment of fresh oil. Studies done with french fries indicate that oil can be replenished three times within 100 hours of frying time, and the hydrolytic and oxidation products are diluted, thus maintaining the sensory value of oil (Thompson and Aust 1983). It is recommended that the removal of frying oil for french frying occurs when the polar compounds reach 20%, and the rejection of oil when the polar compounds reach 25% (Poumeyrol 1986).

Hydrogenation can affect the sensory quality of oil. Blumenthal et al. (1976) found that the sensory quality of french fries fried in hydrogenated soybean oil decreased as compared to non-hydrogenated soybean oil fried under the same conditions. Each type of oil will have its on flavor profile. Off-flavor compounds produced by polyunsaturated fats have been characterized by consumers as "grassy," "fishy," and "rancid" (Sinram and Hartman 1989). Min and Smouse (1989) described the two disadvantages of using

hydrogenated oil. One disadvantage is that hydrogenated oil has a lower linoleic acid content, which causes less full and less pleasant flavors. Another disadvantage is that hydrogenated oil has different oxidation products as compared to natural fats. These peculiar products can produce unfamiliar off-flavors and odors to the oil and the product being fried.

In addition, appearance plays a role in the acceptance of a fried product. French fries are expected to be light in color, with little browning. During frying, Maillard (non-enzymatic) browning can occur. This involves the reaction of sugars with free amino acids or free amino groups of proteins and peptides (Boskou and Elmadfa 1999). To avoid the development of dark colors while frying, potatoes with lower sugar content are selected.

Nutritional implications

The American Heart Association and the American Dietetic Association to name a few, recommend diets high in whole grains, fruits, and vegetables, and low in total fat. It is recommended that fat calories consumed should be less than 30% of total calories. Twenty years ago, the fat calories consumed was 40% of total calories, currently it has decreased to 33% (Inform 1999b). However, this is deceptive because fat consumption has actually increased as total calories consumed have increased. Due to the public's increased awareness of saturated fat and cholesterol, there has been a surge in consumption of vegetable oils and a decline in consumption of animal fats such as lard and butter and highly saturated vegetable oils such as palm and coconut oils. Many studies

have shown that saturated fatty acids appear to increase the risk of coronary heart disease (CHD) by increasing low density lipoprotein-cholesterol (LDL-C) (with the exception of stearic acid which has no effect). Monounsaturated fatty acids (MUFA) actually reduce plasma cholesterol, and polyunsaturated fatty acids (PUFA) are beneficial in reducing CHD risk by lowering blood LDL-C (omega-6 fatty acids) and/or triglyceride levels (omega-3 fatty acids) (Nelson 1998). In a meta-analysis study, experimental diets were designed to determine the effects of MUFA and PUFA on blood lipid profiles. It was found that both diets elicited similar lowering effects of LDL-C levels in parallel with total cholesterol, however MUFAs did not lower HDL-C levels whereas a slight decrease was seen with PUFAs (Mensink and Katan 1990). The composition of various fats and oils are summarized in Table 4.

Of course, consumers have responded to this by markedly reducing butter consumption from their diet and replacing it with the "healthier" margarine. However, recent studies indicate that this replacement for butter may not be so good for the heart after all. This is due to the fact that margarine contains trans fatty acids produced during the hydrogenation of vegetable oils.

From the 1950s to 1990s, french fries were cooked in beef tallow, which gave the fried food a smooth, buttery taste. Public concern about the health risk associated with the cholesterol found in animal products prompted fast food restaurants to change to vegetable oil for frying (Gladwell 2001).

During 1989 and 1990, many restaurants reduced their use of saturated fats and substituted hydrogenated vegetable oils due to consumer pressure for healthier products

Table 4. Typical composition of the principal vegetable and animal fats and oils in the U.S.[1,2]

Dietary fat	Saturated fat (%)	Polyunsaturated fat (%)		Monounsaturated fat (%)
		Linoleic	Alpha-linolenic (an omega-3 fatty acid)	
Canola oil	6	22	10	62
Safflower oil	9	78	0	13
Sunflower oil	12	68	0	19
Corn oil	13	58	1	28
Olive oil	17	10	1	72
Soybean oil	15	54	7	24
Peanut oil	14	32	0	50
Cottonseed oil	26	54	1	20
Lard	42	10	0	48
Palm oil	50	10	0	40
Beef tallow	46	3	1	47
Butterfat	63	2	1	31
Coconut oil	92	2	0	6

[1]Institute of Shortening and Edible Oils 1999.

[2]Fatty acid composition data determined by gas-liquid chromatoghraphy and privided by member companies of the Institute of Shortening and Edible Oils, Inc. Component fatty acids may not add to 100% due to rounding.

(Hunter and Applewhite 1991). Mono- and polyunsaturated fatty acids are considered "heart healthy," however the process of hydrogenation rearranges some of the fatty acids from the cis form to the unhealthy trans form. Partially hydrogenated vegetable oils contain approximately 30% trans fatty acids, whereas tallow contains approximately 3% trans fatty acids (Hunter and Applewhite 1991).

It has been known for years that dietary fat and cholesterol influence blood cholesterol concentrations. Extensive research has been done not only on fats as a class, but on individual fatty acids and their effects on blood lipid levels and lipoprotein concentration. The length of the chain and the degree of unsaturation of a particular fatty acid molecule contribute to the ability of the fatty acid to promote or delay the development of atherosclerosis. Scientists now agree that total dietary fat intake itself is a poor predictor of CHD risk (Nelson 1998). Small differences in fatty acid structures may have huge influences on their metabolic effect (Pederson 2001). For example, myristic acid (14:0) and palmitic acid (16:0) are potent cholesterol increasing fatty acids, while stearic acid (18:0) and oleic acid (cis 18:1) have no effect on serum cholesterol, and linoleic acid (18:2) decreases serum cholesterol (Pederson 2001). Laurate, myristate, and palmitate constitute the majority of saturated fatty acids consumed in the Western diet (Nelson 1998). Trans fatty acids are metabolized in the same manner as saturated fatty acids. A study by Mensink and Katan (1990) found that consumption of trans fatty acids increases blood cholesterol levels. Other studies have shown that saturated fatty acids and trans fatty acids are equal in their effects on blood cholesterol.

Large scale epidemiological surveys and results from human feeding studies all point to the same conclusion, that an increased risk from coronary heart disease is associated with dietary intake of trans fatty acids (Nelson 1998). Zock et al. (1995) hypothesize that for every additional percentage of trans fatty acid in the diet, LDL-C is raised by about 1.5 mg/dl and HDL cholesterol is lowered by approximately 0.5 mg/dl. Huang and Fang (2000), randomly assigned hamsters to three different diets; trans fatty acid diet, saturated fatty acid diet, and polyunsaturated acid diet. It was found that the diets high in trans fatty acid and saturated fatty acid raised serum cholesterol levels as many other previous studies have found. The saturated fat diet significantly increased activity of hepatic acyl-CoA: cholesterol acyltransferase (ACAT) - the key enzyme in cholesterol metabolism, with the trans fatty acid diet was a close second. They proposed that both trans fatty acids and saturated fatty acids are preferred substrates for ACAT. They also proposed that since there is a shared similarity in the configuration of trans fatty acids (which are slightly bent at the double bond) and saturated fatty acids, this is important in facilitating the reaction with ACAT. To complicate matters further, a study by van Greevenbroek and others (1998) found that it may not be just the geometric configuration, but also the specific chain length that effects serum lipid concentrations.

It is important to choose foods with both a low saturated fat content and a low trans fatty acid content. A study by Lichtenstein and others (1999) fed 18 men and 18 women 6 diets in random order for 35-day periods. The diets contained 30% fat and 2/3 of the fat was provided by one of six fat sources (Table 5).

Table 5. Study fat used in the diet.

Fat	Calories from trans fat (%)	Calories from saturated fat (%)
Soybean Oil	0.6	7.3
Semi-liquid margarine	0.9	8.6
Soft margarine	3.3	8.4
Shortening	4.2	8.6
Stick margarine	6.7	8.5
Butter	1.3	16.7

LDL cholesterol was 6% lower with the shortening and stick margarines compared to butter. LDL cholesterol was 7 to 10% lower with soybean oil, semi-liquid (squeeze bottle) margarine and soft margarine diets. The soybean oil and semi-liquid margarine diets had the most favorable overall effects with the soft margarine diet close behind. The butter diet was almost as low in trans fat as the soybean oil and semi liquid margarine diets, but the saturated diet and cholesterol were higher which caused butter to have the worst overall effect.

Nelson (1998) cautions against concluding that trans fatty acids are a major contributor to CHD. Although there are many well-conducted studies, they are not without error. Without the use of capillary gas chromatography, which was not routinely done in past studies, it was difficult to assess the amount of trans fatty acids in foods (Nelson 1998). The food supply is constantly changing and compositional data is just one point in time (Allison et al. 1999). The two approaches used in many studies was to measure mortality or morbidity as endpoints or measure changes in plasma cholesterol or lipoprotein levels, and these two approaches may not be equivalent (Nelson 1998). Nevertheless, since consumption of trans fatty acids does not appear to be beneficial, and the evidence strongly points to the fact that it can be detrimental, it is reasonable to decrease their intake.

Given this new information, many restaurant chains are now considering switching to unhydrogenated vegetable oils. Cottonseed oil contains only 3 grams of saturated fat per teaspoon, and contains less than one tenth of one percent trans fatty acids (NCPA 1996). In addition, since cottonseed oil is naturally heat stable, it is not necessary to

hydrogenate the oil to increase its stability. Therefore, cottonseed oil contains fewer trans fatty acids than hydrogenated oils, putting it into the "heart healthy" category.

Allison et al. (1999) estimated the trans fatty acid intake of Americans by using food intake data from the 1989-1991 Continuing Survey of Food Intakes by Individuals (CSPII) and the trans fatty acid contents of foods contained in a database compiled by the USDA. It was found that the mean percentage of energy ingested as trans fatty acids was 2.6% and the mean percentage of total fat ingested as trans fatty acids was 7.4% (5.3 grams of trans fatty acids per day). Of this value, only 20-25% of the trans fatty acid intake comes from naturally occurring sources (basically animal fats), where as the majority of the intake comes from altered fats. Since the 1960s, levels of trans fatty acids in margarines have declined as softer margarines have arrived on the market due to health concerns (Ascherio et al. 1999). In the mid 1980s, manufactures replaced partially hydrogenated vegetable oils used in household salad and cooking oils with unhydrogenated vegetable oils (ASCN 1995). The majority of trans fatty acids consumed today come from fried foods, margarine, snacks and baked products (Table 6). For example, a large cake doughnut has 3 g of trans fatty acids and a large order of french fries has 5 grams of trans fatty acids (Lichtenstein et al. 1999). Trans fatty acids should be limited to no more than 3 g/day (Lichtenstein et al. 1999).

The information above indicates that trans fatty acids may have detrimental effects on health. However, it is hard to recognize foods that are high in trans fatty acids because they are not listed on the food label. For decades, trans fatty acids have been included

Table 6. Per capita contribution of trans fatty acids in primary food sources[1&2]

Food source	Total fat (g/d)[5]	Trans fat (g/d)
Vegetable		
Bread, commercial	4.0	0.3 (0.0-1.3)[6]
Fried foods[3]	3.9	0.8 (0.1-1.3)
Cakes and related baked goods	2.9	0.3 (0.3-0.4)
Savory snacks	2.3	0.3 (0.0-0.9)
Margarine, stick[4]	1.7	0.5 (0.3-0.8)
Margarine, soft and spreads[4]	1.2	0.2 (0.1-0.3)
Cookies	1.2	0.2 (0.2-0.4)
Crackers	0.5	0.1 (0.1-0.2)
Household shortenings	0.4	0.1 (0.0-0.1)
Animal		
Milk	5.5	0.2 (0.1-0.2)
Ground beef	3.4	0.1 (0.0-0.1)
Butter[4]	1.3	0.1 (0.1-0.2)

[1] Adapted from ASCN, 1995.
[2] Values are 3d averages from the USDA Continuing Surveys of Food Intakes by Individuals, 1989-1990 and 1990-1991. Trans composition data adapted from Nutrient Data Bank Bulletin Board (US Department of Agriculture/Agricultural Research Service, Riverdale, MD) and Dickey, 1995.
[3] Home and food service combined.
[4] Intake of these foods does not include use as ingredients in foods already listed in table.
[5] Total fat intake = 69 g/d; total energy intake = 1758 kcal/d.
[6] Range in parentheses.

among the monoene fatty acids, thus giving the erroneous impression of a fairly favorable nutritional quality (Pedersen 2001). Because trans fatty acids have become such a hot topic, the Food and Drug Administration (FDA) is proposing that trans fatty acid content be included on the food label. The FDA would require that trans fat be included on the food label in the "daily value per serving" listing for saturated fat. Foods containing trans fatty acids would have to provide a footnote by the saturated fat value with the amount of trans fatty acid in fat grams per serving. Products containing less than 0.5 g trans fatty acid per serving could claim "trans fat free" on their labels (Inform 1999c) (Figure 2). This is going to cause a major stir in the foodservice industry. Companies that have been able to claim that their products are low in saturated fat and therefore are "heart healthy," may be faced with huge losses in sales when they are forced to add the amount of trans fatty acid content to their labels. This may make it possible for cottonseed oil to increase its niche in the market and improve its reputation as a "heart healthy" oil.

The proposed labeling requirements will be very informative for those consumers who are knowledgeable about the effects of trans fatty acids. However, the majority of consumers do not even know what the term means. An article in Inform (1999a) cited consumer surveys in which only 34% of consumers could make an educated food selection when looking at saturated fat content. Only 4% said they could make an informed decision regarding information about trans fatty acids. Education will play an integral role in determining whether disclosing trans fatty acids on the label will actually change behavior patterns towards a healthier diet in the consumer.

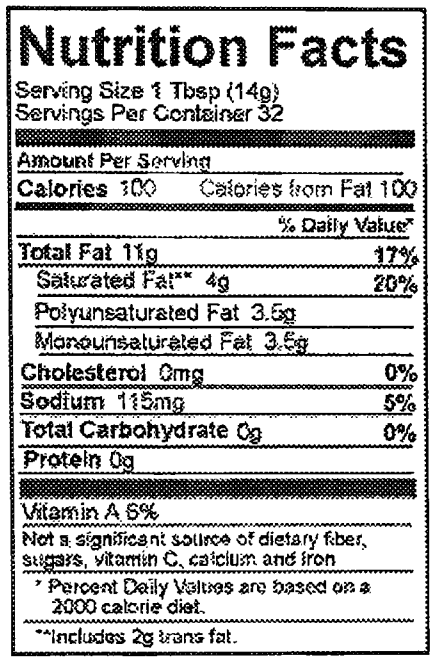

Figure 2. Proposed FDA food label (Inform 1999c).

The goal for the future is to decrease the amount of trans fatty acids in foods, in addition to decreasing the total amount of fat consumed. The advantage of using cottonseed oil is the fact that it does not require hydrogenation.

Hydrogenation

The hydrogenation process can be refined so that fewer trans fatty acids are produced by refining the processing conditions (e.g., temperature, catalyst, pressure, intensity of agitation and starting oils) and methods used (American Society of Clinical Nutrition 1995), however, this will take time and money.

Selectivity in hydrogenation means a preference for hydrogenating one class of unsaturated substances rather than another and maintaining this preference until the concentration of the preferred unsaturate is greatly decreased (Patterson 1983). Another definition of selectivity adopted by the USDA is the ratio of the reaction rates of the hydrogenation of linoleic acid compared with the hydrogenation of oleic acid (Gray and Russell 1979). Selectivity and isomer formation is determined by the concentration of hydrogen adsorbed on the catalyst (Allen 1978). Temperature, catalyst, pressure, intensity of agitation and oil type all effect hydrogen concentration, thus affecting selectivity. An increase in temperature during hydrogenation increases the speed of the reaction and causes a faster removal of hydrogen from the catalyst, thus increasing selectivity (Fennema 1985). Several temperature levels exist at which critical effects for the course of the reaction are obtained (Patterson 1983). An increase in temperature will also increase trans fatty acid formation (Puri 1980).

A catalyst is a substance that increases the reaction rate of a process, but is not present in the final product. The most widely used commercial catalyst for oil hydrogenation is nickel supported on an inert substance (Puri 1980). Nickel catalysts are advantageous due to their wide availability, low cost and inert nature (Puri 1980). However, the limitations of hydrogenation with nickel include selectivity, which is never absolute, resulting in little preference for linolenic acid over linoleic acid, and large amounts of trans-fatty acids are formed (Puri 1980). The use of Pd and Pt catalysts are not very popular due to the formation of trans isomers and copper-chromite catalysts have high selectivity but low activity (Puri 1980). The use of other metals such as copper, platinum and palladium are other possibilities (Naglic et al. 1998).

Pressure indirectly affects the reaction rate of hydrogenation by speeding up the rate of solution of hydrogen into the oil, thus increasing the hydrogen supply to the surface (Patterson 1983). At higher pressures (500 psi), the reaction is nonselective since di- and trisaturated glycerides are formed at about 70 iodine value, whereas at 50 psi, the reaction becomes selective (List et al. 2000). In addition, higher pressures lead to more trans fatty acid formation (Puri 1980).

Agitation mixes the catalyst uniformly with the oil, aids in dissolving the hydrogen in the medium, and releases heat. Increased agitation increases the hydrogen concentration in the oil (Patterson1983). Low agitation results in higher selectivity but also more trans fatty acids (Fennema 1985).

Oil type will also affect the hydrogenation process. For example, all oils vary in types of triglycerides present and degree of saturation. Each oil will respond differently to

hydrogenation and the entire process, from cleaning prior to hydrogenation to the temperature used are unique to that particular oil.

Selectivity allows the processor to exert considerable amount of control over the properties of the final oil by changing the process conditions as described above (Fennema 1985). However, as selectivity of the reaction increases, so does the formation of trans isomers (Fennema 1985).

Another processing technique that companies can use for oils that require hydrogenation in order to increase their stability is interesterification. Interesterification rearranges the distribution of fatty acids on the glycerol backbone without changing their chemical composition (Liu and Lampert 1999). This produces a product with low or zero trans fatty acids (Liu and Lampert 1999). Interesterification of liquid oils with solid fats will likely increase in the future once the process is well controlled and the cost can be reduced. However, this process will also take time and money to develop.

Summary

Cottonseed oil was very popular before less saturated oils took its place in the snack food market. Saturated fatty acids are linked to heart disease and other health related concerns. However, due to the increased mono- and polyunsaturated fatty acid content of canola and soybean oil, they must be hydrogenated to increase the stability. Hydrogenation changes some of the mono- and poly-unsaturated fatty acids that might be less "heart healthy." Cottonseed oil can once again become a leader in the food industry

once people - both consumers and industry - are aware of the healthy and cost containing properties of the oil.

CHAPTER III

MATERIALS AND METHODS

Materials

Fat sources

Cottonseed oil was obtained from Pyco Industries, Lubbock, Texas; both Extend® (canola oil), and Mel Fry® (soybean oil) were obtained from Ventura Foods LLC, City of Industry, CA. Canola oil and soybean oil were chosen because they are the two most commonly used frying oils in the restaurant industry. Cottonseed oil was not hydrogenated, while canola and soybean oil were partially hydrogenated. All three oils contained TBHQ and citric acid as an antioxidant and dimethylpolysiloxane as an antifoam agent.

Food

This research was conducted using USDA grade "A" quality frozen, partially cooked, Russet Burbank potatoes produced by Payette farms (J.R. Simplot® product), straight cut 3/8" x 3/8" The nutritional composition of an 86 g (3 oz) serving size is 120 calories, 4 g fat, 1 g saturated fat, 18 g carbohydrate and 2 g protein. In addition to potatoes, the ingredients consisted of beef tallow and/or vegetable shortening (partially hydrogenated soybean and/or canola oil), dextrose, disodium dihydrogen pyrophosphate (to maintain natural color). The french fries were obtained from Watson Sysco

Foodservice (Lubbock, TX). See Appendix B for the product information specification sheet.

Fryer

A stainless steel, gas heated deep-fat fryer with three 23-27 kg (50-60 pound) oil capacity tanks (Pitco Frialator® with built in filter, model AG14S, Pitco Frialator Inc., Concord, NH) was used. For statistical purposes, each tank was considered a block.

Experimental design

Using a block (tank) design with a split plot (time), each of the three tanks was filled to capacity with its designated fresh oil. The oil was placed into a container tared on a bench scale, and approximately 24 kg (measured to 2 decimal places) was weighed. Once the oil was weighed, it was hand poured back into the fryer. The oil residue left adhering to the walls of the container was scraped into the tank with a large rubber spatula. Each oil was rotated through each tank to correct for any temperature differences between the tanks. Three repetitions were used in order to create a stronger statistical model. One repetition was equal to 3 weeks. Oil was heated and used for 5 consecutive days without replenishing. Although it is typical in a restaurant setting to replenish frying oil, for the purposes of accurately determining deterioration of the oil, the oil was not replenished. The oil was heated for 8 hours every day for five days. This time factor was chosen as the minimum time most restaurants heat their oil. It is typical for restaurants to heat their oil for longer than 8 hours, however, for research purposes, it was not practical

to heat the oil for longer than 8 hours. After five days of heating and frying, the used oil was sampled and discarded and fresh oil was rotated to another tank until each oil had been in each tank during the 3-week repetition. A fresh sample of the oil was taken prior to the start of the study and a sample was taken at the end of each day for analysis. The samples were flushed with nitrogen to help retard oxidation and stored frozen in brown Nalgene containers until further analysis could be performed. At the end of the day, the oil was filtered using the built in filtering system within the Pitco Model AG14S. Prior to draining the oil for filtering, 1 cup of filtering powder (Homestyle® Hol-N-One, Inc. Fordyce, AR 71742) obtained from Lubbock Restaurant Supply (Lubbock, TX) was added to the oil. This is a common practiced that is used in the food service setting to extend the life of the oil. As the oil was draining, any food particles around the sides of the fryer or left in the bottom were scraped towards the drain. The oil in the last tank (farthest from the filtering system) was filtered first, the middle tank second, and the tank closest to the filter last. This minimized contamination of the different types of oil. Fresh filter paper was used to filter each oil type. The filtering process was timed using a digital timer for exactly 2 minutes. The oil was pumped back into the same tank by the fryer's internal pump and allowed to bubble. This signified that the return lines had been cleared. This pumping process was timed for exactly 2 minutes.

At the beginning of each day, the oil was pumped out of the tank using an external pump fitted with plastic, clear hosing attached with screw clamps into a large container tared on a bench scale, and weighed to the nearest $1/100^{th}$ of a kg to determine oil loss. The oil clinging to the sides and bottom of the tank that was not removed by the suction

of the pump, was scraped using a large rubber spatula, suctioned using a turkey baster and emptied into the container. Once the oil had been weighed, it was hand poured back into the fryer. The oil residue adhering to the walls of the container was scraped into the tank with a large rubber spatula. To prevent contamination, the spatula was cleaned before contacting each oil type. There were 3 containers and 3 turkey basters labeled with the oil type. All equipment was washed with hot water and dishwashing soap after each use. After the 5-day cycle, the fryer was cleaned first with Drano®, rinsed with water, cleaned again with apple cidar vinegar, rinsed, and dried.

A poll was taken from restaurants in the Lubbock area and based on the results of this poll, a temperature of 177° C was selected as the temperature that would be used to cook the french fries. Frozen french fries were taken from the freezer and immediately weighed to the nearest $1/1000^{th}$ of a kg. Approximately 2 kg of french fries were added to the deep-fat fryer basket and immersed in the hot oil at a temperature of 177 ° C for exactly 5 minutes. A digital timer was used to accurately record the time. Throughout the day, 6 batches of fries were cooked, yielding daily a total of 12 kg (26.4 pounds) of french fries for each oil. Batches were fried every 30 minutes to an hour to allow the temperature of the oil to recover between batches. The fries were then removed from the oil and allowed to drain for 2 minutes. Through preliminary testing it was determined that 5 minutes was the time that produced the most consistent results (color and a cooked product throughout). Two kg's of french fries filled the fryer basket to half capacity, this level allowed the french fries to adequately cook even if the oil level was extremely low at the end of the fifth day. Once the fries were drained, they were weighed and colorimeter

values were determined for batches 1, 3, and 6 using a Minolta CR 200 colorimeter. Batch 6 was vacuum packaged (brand) and stored frozen for analysis. In addition, batches 1 and 3 were also vacuum packaged and stored frozen in case there was a trend in the results that needed to be further investigated.

Lab analyses

Iodine value, peroxide value, p-anisidine value, free fatty acids, totox value, fatty acid profile, and trans fatty acid profile were performed in duplicate on oil samples. Crude fat, moisture, total polar materials, fatty acid profiles, and trans fatty acids were performed on the french fries.

Iodine value

Iodine value was analyzed using the AOCS Official Method (Cd 1-25; 1998) with slight modifications. Fifteen ml of chloroform solution was added to 0.40g of filtered canola oil and soybean oil (Iodine value of approximately 80) and 0.25g of cottonseed oil (Iodine value of approximately 120). Twenty-five ml of WIJS solution was dispensed into the flask containing the sample, and stored in the dark for 30 minutes. Once the flasks were removed from storage, 20 ml of KI solution was added, followed by 100 ml of distilled water. The solution was titrated with 0.1N sodium thiosulfate until the yellow color almost disappeared. One to two ml of starch indicator was added and the titration was discontinued when the blue color just disappeared. This same procedure was conducted on a blank sample. The iodine value was expressed as g halogen/100g fat using

this calculation: [(ml Blank-ml Sample) x N of sodium thiosulfate x 12.69] divided by sample weight (g).

Peroxide value

Peroxide value was analyzed using AOCS Official Methods (Cd 8-53; 1998). Thirty ml of acetic acid/chloroform solution (3:2, v/v) was added to a flask containing five grams of sample. Saturated potassium iodide was added (0.5 ml) to the solution and allowed to stand for 1 minute while occasionally shaking the flask. Distilled water was added (30 ml), and the solution was titrated with 0.012 N sodium thiosulfate until the yellow color almost disappeared. Starch indicator (0.5 ml) was added and the titration was continued until the blue color disappeared. The peroxide value was expressed in meq peroxide per kg sample using this formula: (ml of sample x N sodium thiosulfate x 1,000) divided by sample wt (g).

Free fatty acids

Free fatty acid values were analyzed using AOCS Official Methods (Ca 5a-40; 1998). Hot neutralized alcohol and 2ml of phenolphthalein was added to 28.2 g sample. The solution was titrated with standardized sodium hydroxide, shaking until the first permanent pink color of the same intensity as that of the neutralized alcohol. The color had to persist for 30 seconds. Free fatty acid values were expressed as % oleic, using this calculation: (ml of alkali x N of NaOH x 28.2) divided by sample wt (g).

p-Anisidine value

p-Anisidine values were analyzed using AOCS Official Methods (Cd 18-90; 1998). Approximately 0.5-4 g of oil was weighed into a 25 ml volumetric flask. The sample was dissolved and diluted to volume with isooctane. The absorbance of the solution at 350 nm was measured in a cuvette with the spectrophotometer, using the reference cuvette filled with the solvent as a blank. Exactly 5 ml of the fat solution was pippetted into one test tube and exactly 5 ml of solvent into a second test tube. By means of an automatic pipet, exactly 1 ml of the p-anisidine reagent was added to each tube, and shaken. After exactly 10 min, the absorbance of the solvent was measured in a cuvette at 350 nm, using the solution from the second test tube as a blank in the reference cuvette. The p-anisidine (p-AV) value is given by the formula:

$$\text{p-AV} = \frac{25 \times (1.2As - Ab)}{m}$$

where As = absorbance of the fat solution after reaction with the p-anisidine reagent; Ab = absorbance of the fat solution, m = mass of the test portion in grams.

Fatty acid profile of the oil

Fatty acid profiles on the oil samples were analyzed by Texas A&M Agricultural Research and Extension Center. The methylation procedure is as follows:
The methylation mix consisted of 29.1 ml of 14% BF_3 in MeOH (Borontriflouride in Methanol), 20.0 ml of Toluene and 50.9 ml of MeOH (Methanol). One drop of oil was added to a labeled Pierce Reactivial. Approximately 1.5 ml of methylation mixture was

added. The vial was sealed with a lid and septum and block heated at 100°C for 30 minutes (vials were shaken at the 15 minute point). Vials were allowed to cool and approximately 1.5 ml of distilled water was added to the vials. This solution was decanted into large labeled test tubes. The solution was extracted twice with 1.5 ml of Hexane (each extraction was vortexed and top layer was pipetted off into small labeled test tubes). The extractant was dried under Nitrogen gas. Residue was dissolved with 1.0 ml of Chloroform and decanted into labeled vials. One micrometer was injected into the Hewlet Packard Gas Chromatagraph. Gas Chromatography specifications are as follows: Column: Supelco Supelcowax 10, 30 m x 0.53 mm, 0.50 ④m Film; Flow Rates: Helium: 22.4 ml/min, Hydrogen: 22.36 ml/min, Air: 448.6 ml/min, Septum Purge: 4.17 ml/min, Split Vent: 70.6 ml/min, Split Ratio: 4.17; Injector Temperature: 200°C; Flame Ionization Detector Temperature: 250°C; Oven Temperature Program: Initial 210°C, Final 240°C, Rate of increase 4°C degrees/min; Auto Sampler: Rinse 3x hexanes, Rinse 2x chloroform, Rinse 2x sample, Pump syringe 4x to remove bubbles, Inject 1 ml solution.

Fatty acid profile of the french fries, trans fatty acids and total polar materials

Fatty acid profiles of the french fries, trans fatty acid content of the french fries and oil, and total polar material content of the french fries were analyzed by Analytical Food Laboratories, 865 Greenview Drive, Grand Prairie, Texas 75050-2439, 1 (800) 242-6494.

Statistical analyses

A randomized block design with split-plot was used to analyze the data collected. The tank effect was blocked out in the statistical design. The split-plot was time in days (days 1-5). The dependant variables were weight of the french fries, oil loss, color of the oil, color of the french fries, and the results of the laboratory analyses. Least Square Differences (LSD) was used as the means separation tests. Least square means were used instead of sample means to account for missing data in the data set. Standard error was used to show sampling distribution, which is the standard deviation of the population being sampled.

CHAPTER IV

RESULTS AND DISCUSSION

Oil loss

Oil loss was calculated by measuring the difference between the oil amount in the tank prior to frying and the oil left in the tank after frying (units used were kilograms). This calculation was done at the beginning of each day by weighing the oil prior to adding it to the frying tanks, and reweighing the oil after frying. ANOVA was conducted on the independent variables oil type, tank, day, oil type*day, and oil type*day*tank. There were no interactions between oil type*day and oil type*day*tank so only the main effects will be described. LSD was used as a mean separation test. There was no statistical effect of oil type on oil loss. Statistical differences ($p<0.05$) were found for days of frying on oil loss (Figure 3). Oil loss was greatest on day 1, with only slight differences on days 2-5.

French fry cooking loss

French fry cooking loss was calculated as the difference between frozen french fry weight (approximately 2 kg) prior to frying and french fry weight after frying (allowing a 2 minute drain time). ANOVA was conducted on the dependent variables oil type, tank, day, oil type*day, oil type*tank, tank*day and oil type*day*tank. LSD was used to separate differences among means. There was an oil type*tank interaction. There was no significant effect of oil type on french fry cooking loss. However, there was a difference in cooking loss for tank and day.

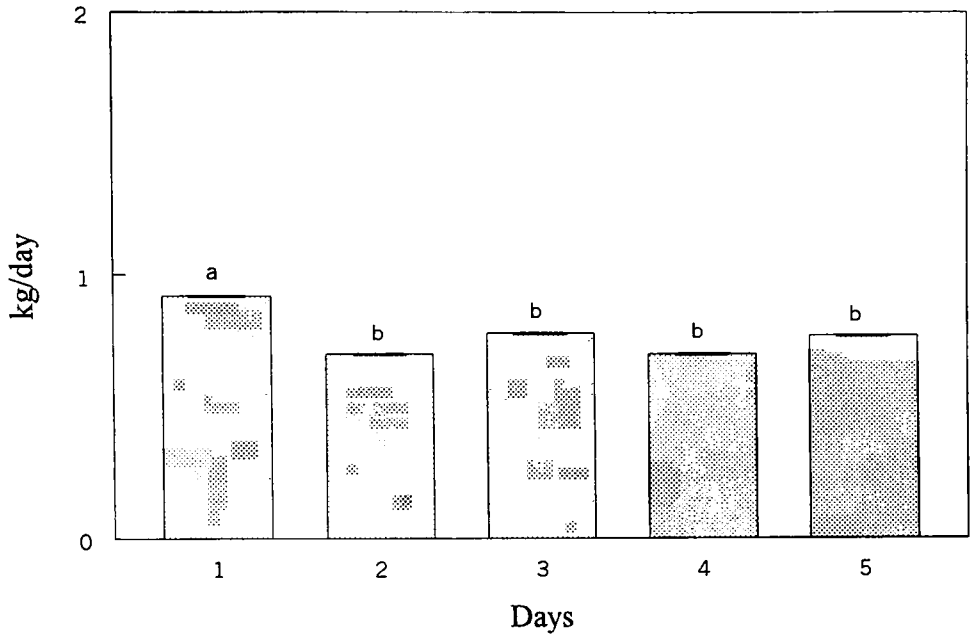

Figure 3. Oil loss for cottonseed oil, canola oil, and soybean oil (combined) on days 1-5.

There was a significant difference ($P<0.05$) between all 3 tanks in french fry cooking loss (Figure 4). French fries fried in the middle tank had the greatest loss (0.662 kg), while french fries fried in tanks one and three lost 0.627 kg and 0.639 kg, respectively. French fries fried in tank two lost more weight than french fries fried in the other two tanks because tank two had a quicker recovery time. Therefore, the french fries in this tank were cooked longer at a temperature of 177°C, and lost more moisture. Tank two was able to gain heat quicker because it was the middle tank, surrounded by heat from the two outside tanks.

A significant effect ($P<0.05$) was found for french fry cooking loss on days of frying (Figure 5). French fries lost the greatest amount of weight on Day 1 and with each consecutive day, weight loss decreased. Days 1 and 2 were significantly different from days 4 and 5, while day 3 was significantly different from day 5. One reason why the greatest amount of weight loss occurred on day 1 and the least amount of weight loss occurred on day 5 may have been due to the amount of oil in the tank. On day 1, the amount of oil was the greatest. This resulted in full coverage of french fries with oil. More moisture was lost because heat was able to penetrate all fries consistently. On day 5, the oil was at its lowest point (oil was not replenished during the 5 days of frying). This resulted in partial coverage of the french fry. It is possible that each fry did not have an opportunity to receive the same amount of heat as french fries on day 1, therefore, they lost less moisture.

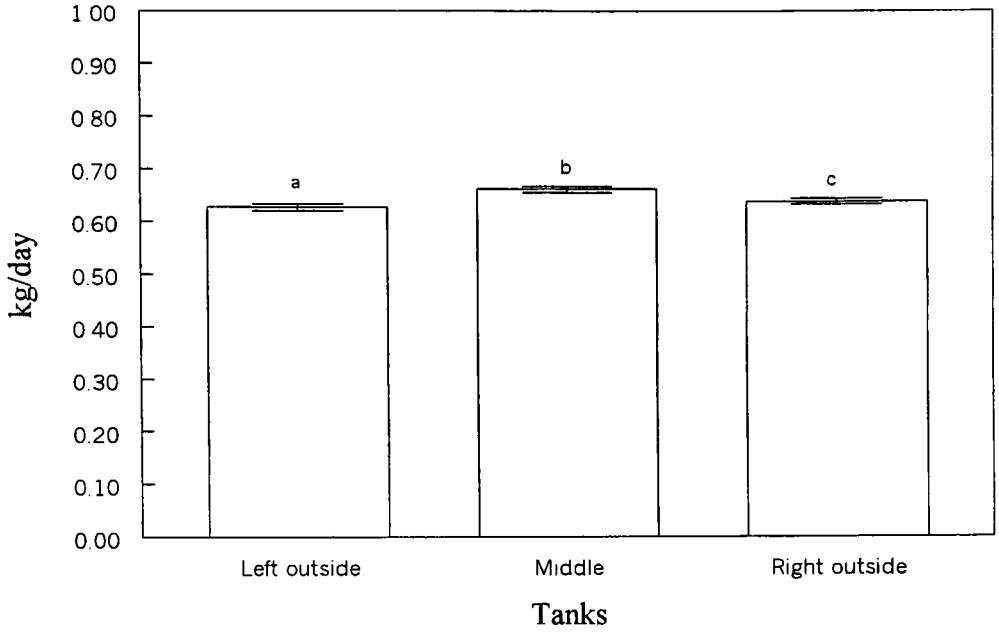

Figure 4. Differences in french fry cooking loss among tanks 1-3 for cottonseed oil, canola oil, and soybean oil (combined).

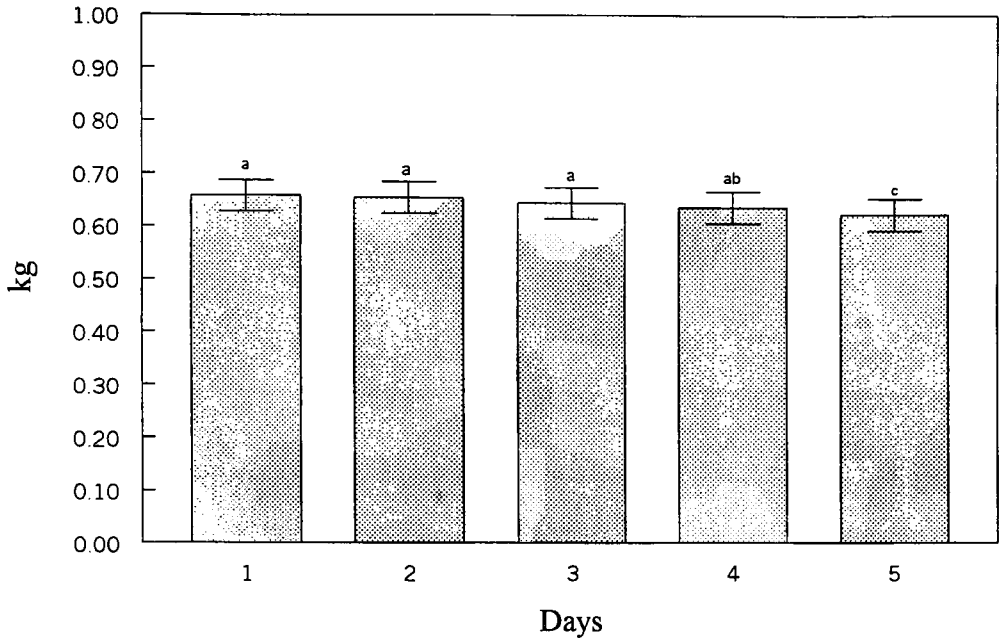

Figure 5. French fry cooking loss for cottonseed oil, canola oil, and soybean oil (combined) on days 1-5.

Color analysis

ANOVA ($p<0.05$) was conducted on the independent variables oil type, tank, day, oil type*day, oil type*tank, tank*day and oil type*day*tank to determine any statistical differences in the L*, a*, b* values for oil. LSD was used for mean separations.

For the value "L", there were no significant effects of oil type, tank, and day. There were no interactions. The mean "L" value for cottonseed oil was 27.45, for canola oil 22.79, and soybean oil 27.92.

There were no significant effects of any of the variables on hue. The mean hue value for cottonseed oil was 61.82 degrees, for canola oil 61.61 degrees, and for soybean oil 60.96 degrees. There was a significant difference among all oil types for chroma. The mean chroma value for cottonseed oil, canola oil and soybean oil was 5.62, 3.06, and 4.61, respectively. This indicates that cottonseed oil had the most vivid color, while canola oil had the dullest color, while soybean oil was intermediate. There were no significant effects of days of frying on chroma. However, as the days progressed chroma changed linearly from 3.87 on day 1 to 4.75 on day 5.

The color of the french fries was also statistically tested using L*a*b* values. No statistical differences were found for L* values on the french fries cooked in the three oils. There were no effects of days of frying or the tanks that the french fries were cooked in and no interactions were found. The average L* value pooled for all oil types was 63.49.

Oil type and days of frying had no significant effect on hue. However, there was a significant difference in hue between the tanks. The mean hue value for tank 1, 2, and 3 was 90.45 degrees, 88.46 degrees and 89.41 degrees, respectively.

Oil type and days of frying had no significant effect on chroma. However, like hue, there was a significant difference between tanks. The mean chroma value for tank 1, 2, and 3 was 21.38, 22.99 and 22.61, respectively.

Lab analyses

ANOVA was used to determine if there were any differences between oil types for peroxide value, iodine value, free fatty acids, and p-anisidine value. LSD was used for mean separation.

Peroxide value

The peroxide value of cottonseed oil was significantly different from the peroxide values of canola oil and soybean oil (Figure 6). Peroxide values cited from the literature in fresh oil should be < 1.0 meq/kg/d. All fresh samples were close to this recommended value, however, cottonseed oil had an initially higher peroxide value (1.08 meq/kg) as compared to canola oil (0.60 meq/kg) and soybean oil (0.42 meq/kg) ($p<0.05$). Peroxide values were higher for cottonseed oil on each day than for canola oil and soybean oil. This may have been due to the higher initial value of fresh cottonseed oil. Peroxide values reflect the initial degradation of unsaturated fatty acid bonds into hydroperoxides. The measurement of peroxide values may be deceptive in polyunsaturated fatty acid (PUFA)-rich oils. A study by Tyagi and Vasishtha (1996) found that oils that contained less trienes had less of a tendency to decompose and polymerize. Fresh, unhydrogenated cottonseed,

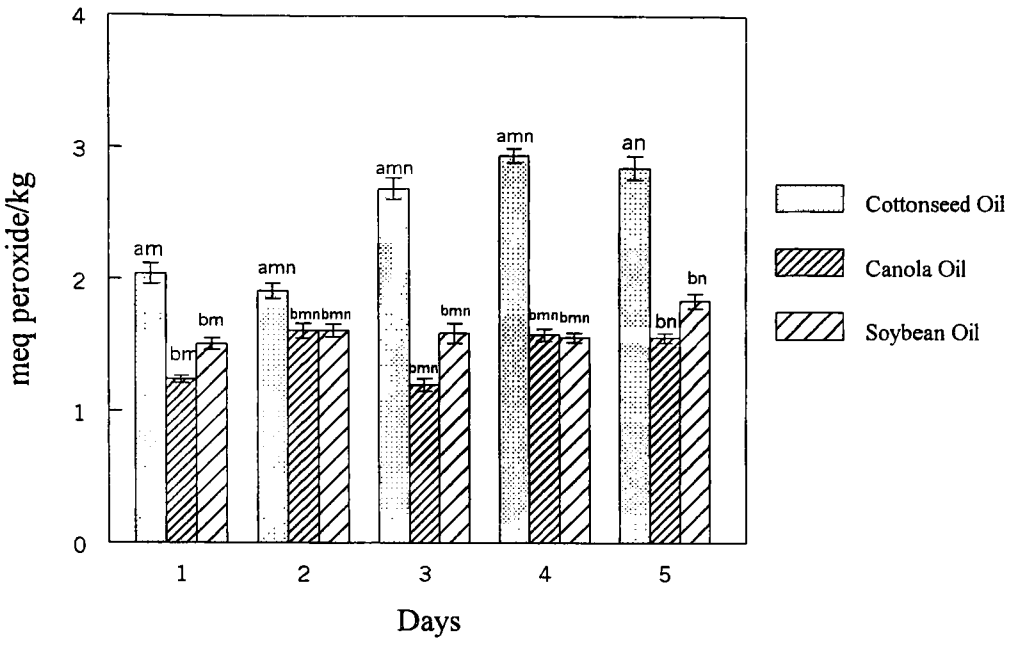

Figure 6. Mean peroxide values of cottonseed oil, canola oil, and soybean oil on days 1-5.

canola and soybean oil contain 54%, 32% and 62% of PUFA. Both the canola and soybean oil used in this study were hydrogenated, thus greatly decreasing the amount of PUFA in the oils.

Furthermore, peroxide values for all three oils were consistently low, indicating very little oxidation was occurring. Studies using soybean oil indicate that peroxide levels ranging from 1.0-5.0 meq/kg signify low oxidation; 5.0-10.0 meq/kg signify moderate oxidation; and 10.0 meq/kg and above signify high levels of oxidation (AOCS 1998). The highest peroxide value was 2.94 meq/kg for cottonseed oil, which is still considered low oxidation levels. None of the three oils in this study surpassed initial oxidative changes according to the peroxide value levels. Peroxide values on day 1 were significantly different from values on day 5. Peroxide values for day 1 for cottonseed oil, canola oil and soybean oil were 2.04 meq/kg, 1.24 meq/kg and 1.51 meq/kg, respectively. There were no interactions in this data set.

Iodine value

Iodine values cited in the literature for fresh cottonseed, canola and soybean oil range from 99-119, 110-126 and 120-143 g of halogen/100 g of fat, respectively. Iodine values obtained from fresh cottonseed, canola and soybean oil in this study were 113.36, 91.92 and 103.82 g of halogen/100 g of fat, respectively. The value for fresh cottonseed oil fell within the range cited in the literature. Since both canola oil and soybean oil were hydrogenated, it is expected that the iodine values would be lower than the literature

values, as was found. Iodine values for used cottonseed oil, canola oil, and soybean oil were all significantly different as expected. Time had no statistical effect on iodine value.

It was expected that there would be a progressive decrease in unsaturation as days of frying increased. There may be two reasons to explain why the iodine value remained stable as frying days increased. All three oils contained antioxidants (TBHQ and citric acid), which may have protected the oil against oxidation. In addition, 40 hours of heating and frying may not have caused enough stress for oxidative changes to occur.

Oil was fried in separate tanks adjacent to each other (Figure 7). The iodine value for tank 2 was significantly different from tank 3. In addition, there was a significant interaction between tanks and oil type. This indicates that the oil may have acted differently depending upon which tank it was in during frying.

Free fatty acids

Free fatty acid (FFA) values for cottonseed, canola and soybean oil were not significantly different. Initial free fatty acid values cited from the literature should be <0.05-0.1% oleic acid. All fresh oils fell within this range (0.045% oleic). Days 4 and 5 were significantly different from days 1, 2 and 3. As expected, free fatty acid values increased toward the end of the frying period (Figure 8). FFA values on day 1 were 0.079%, and on day 5, values increased to 0.256%. According to Fritsch (1981) FFA values of up to 2%, did not adversely affect the odor or the flavor of foods. The practice of using FFA as a measurement of oxidative stability is controversial. Because the determination of FFA by titration does not distinguish between FFA formed from

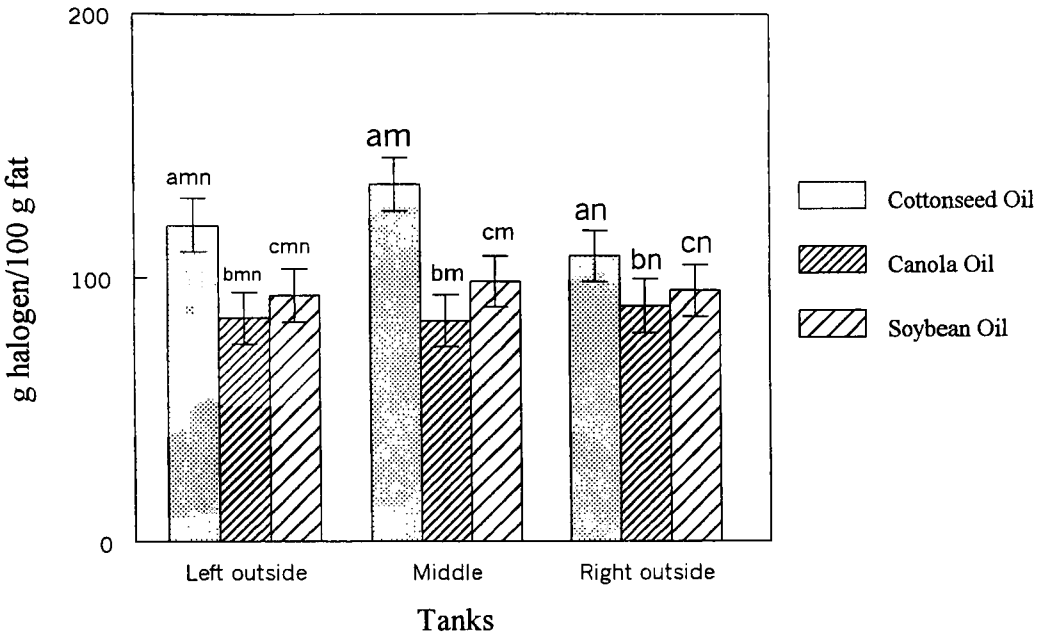

Figure 7. Mean iodine values of cottonseed oil, canola oil, and soybean oil in tanks 1-3.

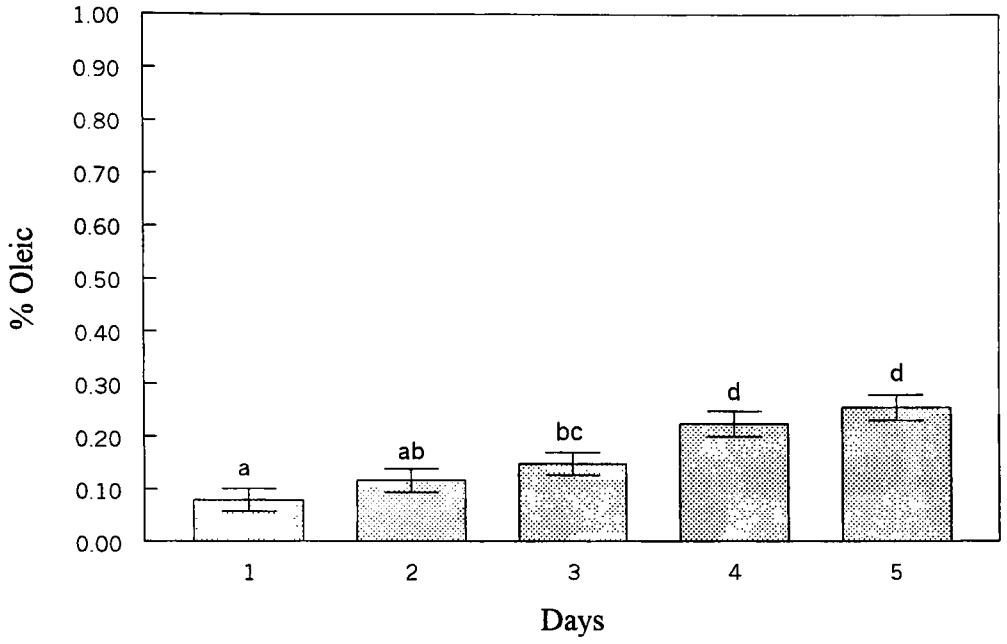

Figure 8. Mean free fatty acid values of cottonseed oil, canola oil, and soybean oil (combined) on days 1-5.

hydrolysis, and FFA formed by oxidation, the increase in FFA may be a poor indicator of frying fat deterioration (Fritsch 1981).

p-Anisidine value

The p-anisidine value is a measurement of secondary oxidation products, principally the aldehydes 2,4-dienals and 2-alkenals (Tompkins and Perkins 1999). Anisidine values of fresh soybean oil should be less than 2.0 to indicate good stability (AOCS 1998). In this study, anisidine values were unable to be taken on the fresh oil samples. Anisidine values for cottonseed oil were significantly different from canola oil and soybean oil on days 1-4. On day 5, canola oil was significantly different than cottonseed oil and soybean oil. On day 1, the anisidine value of cottonseed oil was 15.5, canola oil was 6.73, and soybean oil was 9.65. All values increased as days of frying increased (Figure 9). Day 1 was significantly different from day 5. On day 5, the anisidine value for cottonseed oil was 26.96, for canola oil 19.95, and soybean oil 25.25. The presence of anisidine reactive substances in deodorized oil may indicate prior oil oxidation or damage to the seeds before extraction (AOCS 1998). It is difficult to know whether the anisidine values in fresh cottonseed oil were higher to begin with than the other two oils since values were not available on fresh samples. As the days progressed, the anisidine values of the 3 oils moved closer together.

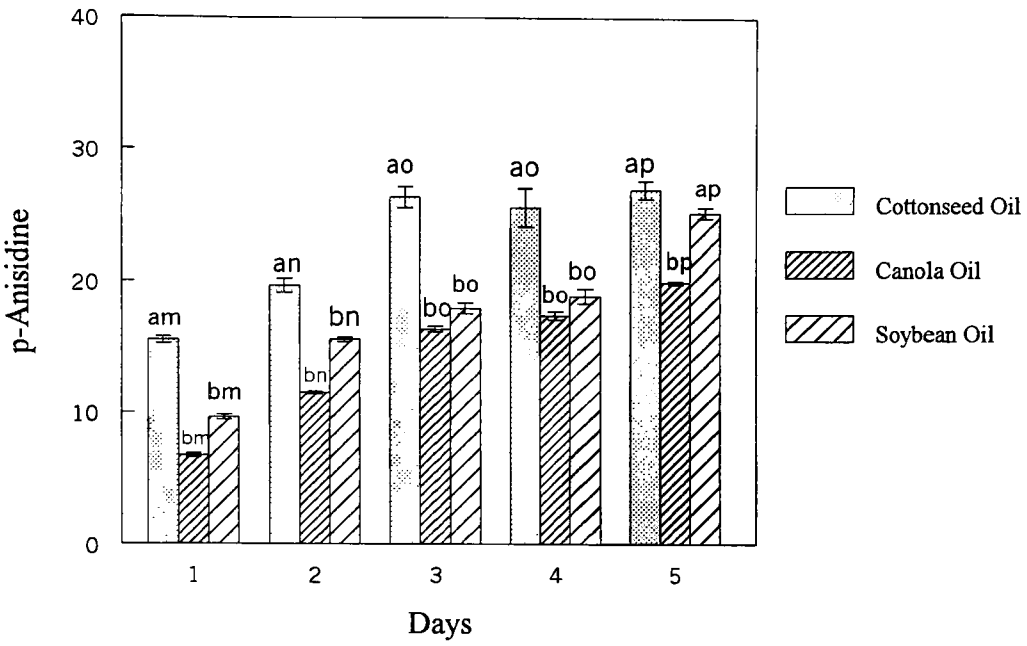

Figure 9. Mean p-anisidine values of cottonseed oil, canola oil, and soybean oil on days 1-5.

Rivera-Acosta (1999) fried 9 batches of french fries, 6 hours/day in cottonseed oil and canola oil (Extend). Para-anisidine values were taken on the fresh oil, and every day for 10 days. Para-anisidine values increased dramatically for cottonseed oil after one day of frying, from a mean of 4.93 for fresh oil, to 42.0 on day 1. Canola oil values were 2.60 for fresh oil, and 12.9 on day 1. Values for cottonseed oil were inconsistent for the first 6 days, but stabilized after day 8 at 38.2. The value on day 10 was 38.1. Canola oil had lower values until day 5. Statistically significant differences were found between oils beginning with fresh oil and continuing through day 5. After day 6 of frying, both oils maintained close values up to the end of the frying period on day 10. This study found similar results as the Rivera-Acosta study for the first 5 days of frying. Cottonseed oil had a rapid increase in ansidine values up until day 3, and values started to level off on days 4 and 5. As frying days increased, soybean oil values became closer to cottonseed oil, while canola oil values consistently trended upwards (Figure 10). Linoleic acid is the predominant fatty acid in cottonseed oil and decomposes quickly into secondary oxidation products. Pentanals and hexanals (aldehydes) were the main volatiles found in the headspace of cottonseed oil (Jones and King 1996). High levels of pentanals and hexanals were not associated with reductions in flavor scores (Jones and King 1996).

Totox value

The use of peroxide analysis and p-anisidine analysis together gives a more complete picture of total oxidation than each test separately (AOCS 1998). The equation

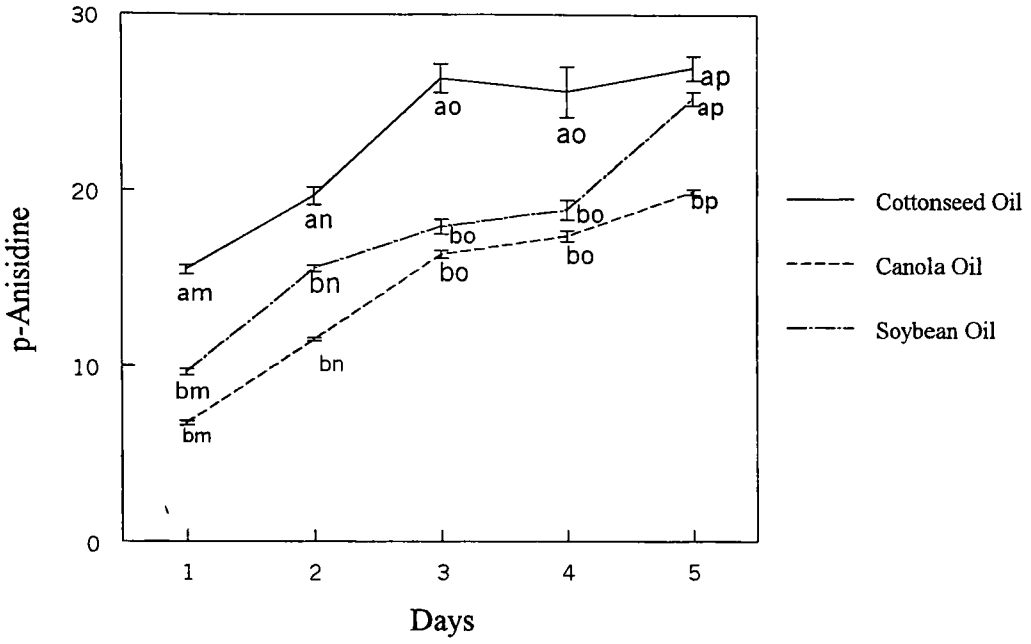

Figure 10. Mean p-anisidine values of cottonseed oil, canola oil, and soybean oil on days 1-5 of frying.

for the totox value is anisidine value + 2 (peroxide value). Since peroxide value measures hydroperoxides (which increase and decrease) and anisidine value measures aldehydes (decay products of hydroperoxides which continually increase), the totox value usually rises continually during the course of lipid oxidation (Nielson 1998). The totox value for fresh soybean oil should be less than 4.0 to indicate good stability (AOCS 1998).

The totox values for cottonseed oil were significantly different from those of canola oil and soybean oil. Days 1, 2 and 5 were significantly different. Totox values on day 1 for cottonseed, canola and soybean oil were 18.58, 9.41 and 12.49, respectively (Figure 11). Totox values on day 5 for cottonseed oil, canola oil and soybean oil were 32.28, 23.39 and 29.13, respectively. For this particular test, the data indicates that cottonseed oil had greater amounts of primary and secondary oxidative products than the other two oils. However, since peroxide values declined as days of frying increased and anisidine values leveled off after 5 days of frying for cottonseed oil, this test may not be truly indicative of oil degradation for this study. More days of frying and temperature abuse would need to be conducted to accurately determine oil quality.

Total polar materials

Total polar materials (TPM) are considered the "gold standard" for measuring oil degradation. Oil usually starts out with 95% of its composition as triglycerides, and ends up upon discard with only 75% of its composition consisting of triglyceride (Blumenthal 1991). Prior to, or at the point in which food service establishments discard their oil, TPM make up approximately 25% of the oil composition (Blumenthal 1991). TPM were

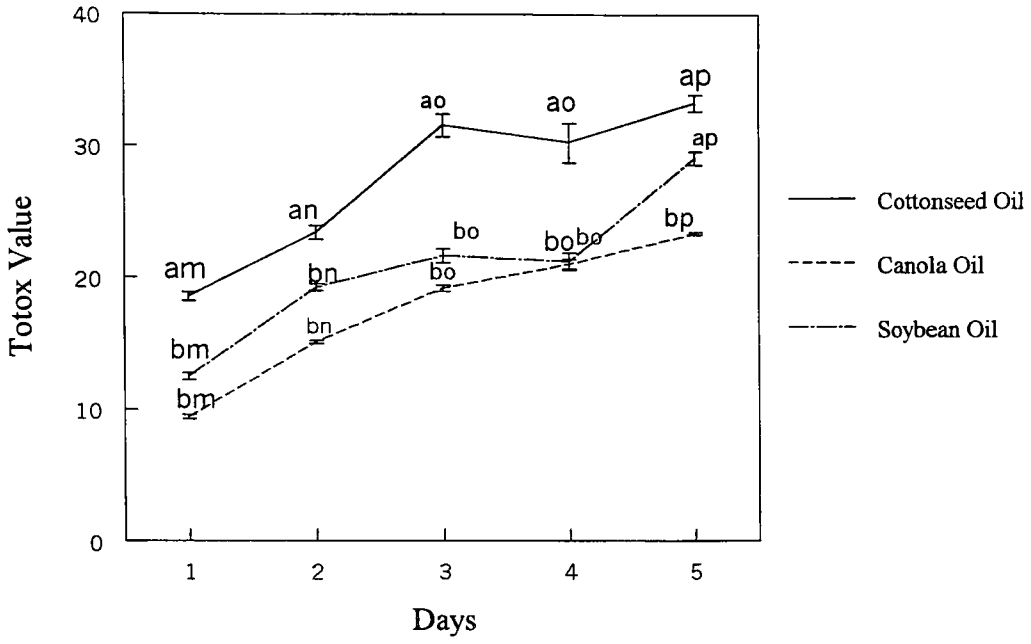

Figure 11. Totox values of cottonseed oil, canola oil, and soybean oil on days 1-5 of frying.

tested on the oil extracted from the raw and cooked french fries. Oil extracted from food contains more polymers than the oil left in the fryer (Pokorny 1980). There was no significant effect of oil type and days of frying on TPM. The average TPM was 22.40%. Since TPM are higher in the food product, and oil is discarded at 25% TPM, this indicates that the oil left in the fryer was not close to reaching the degradation point at which oil must be discarded. The TPM for the raw pre-fried french fries was on average 27.6%. However, only 3 samples were tested and the range was 18.1-41.7%. It was very difficult to extract enough fat from the raw french fries to obtain reproducible results. TPM were not performed on the oil itself.

Fat and moisture content

A significant amount of moisture was lost in the french fries during the deep-fat frying process. This was to be expected since frying is actually a drying process. There was no significant effect of oil type, days of frying (days 1, 3 and 5 were tested) or tank on moisture content. The average moisture content of the raw french fries was 70%, while the average moisture content of the cooked french fries was 51%. Similar results were found in the study done by Filary (1999) at Texas Woman's University. Significant effects were found for both tank and days of frying on the actual weight of the french fries (before and after frying) as discussed above. Weighing the french fries is not as precise as quantitatively measuring the moisture in the french fries. There may have been more ice crystals on some of the raw french fries than others, increasing the variability of measurements. In this case, more moisture would have been lost as vapor rather than

trapped within the french fry. Vapor loss was highest in the middle tank and decreased with increasing days, which attributed to the decreasing oil level.

There were no significant differences in percent fat content of the french fries for cottonseed, canola and soybean oil at any day of the frying process. The initial fat content of raw french fries was 4.1%. The average fat content of cooked french fries was 11.4%. This confirms the results found by Filary (1999). Oil absorption is affected by many factors. As oil deteriorates, oil absorption increases as reported by Blumenthal (1997). In this study, the oil did not reach high enough levels of degradation for this to be seen. Frozen french fries absorb less oil than thawed french fries. This factor was carefully controlled. The french fries were immediately immersed in the oil after being removed from the freezer and were not allowed to thaw. Variation in the french fries can affect oil absorption. Attempts were taken to minimize this effect by analyzing blended, random samples of the french fries. In food-service establishment, french fry shaking and drain time can account for a large percentage of the variation seen in oil absorption. In this study, french fries were not shaken, and were allowed to drain for exactly 2 minutes.

Fatty acid composition of the frying oils

The fatty acids analyzed in this study were palmitic, stearic, oleic, linoleic and linolenic. Figures 12, 13 and 14 show the fatty acid profile of cottonseed, canola and soybean oil, respectively. The fatty acid composition of frying oils will continually change as days of frying progresses. These changes result from cyclization, polymerization, and pyrolytic, hydrolytic, oxidative and other chemical reactions promoted by frying conditions

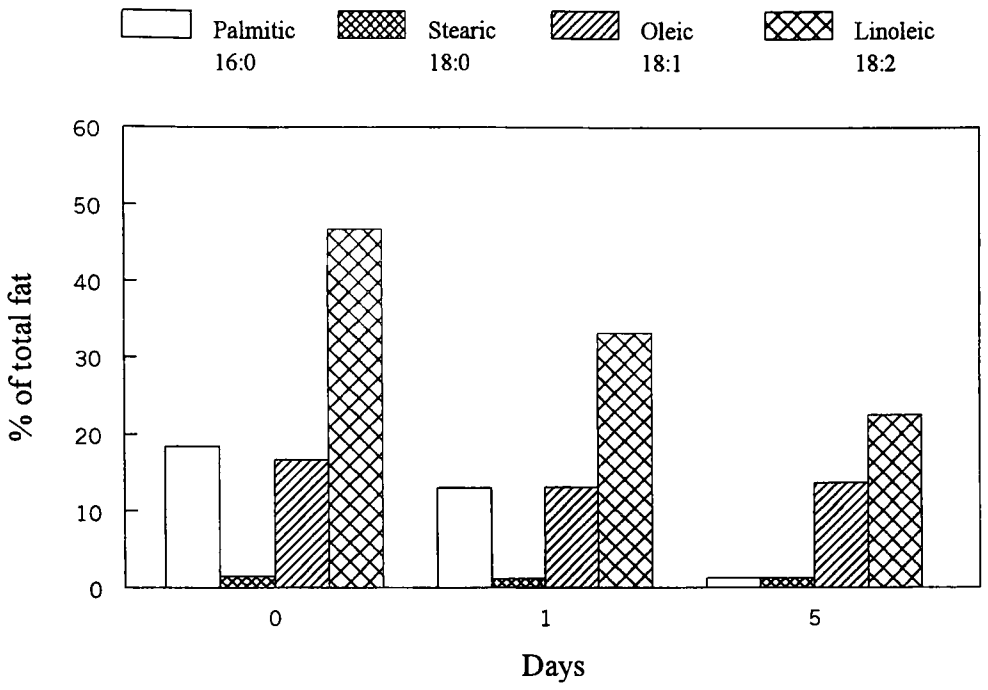

Figure 12. Fatty acid profile of cottonseed oil on days 0, 1 and 5.

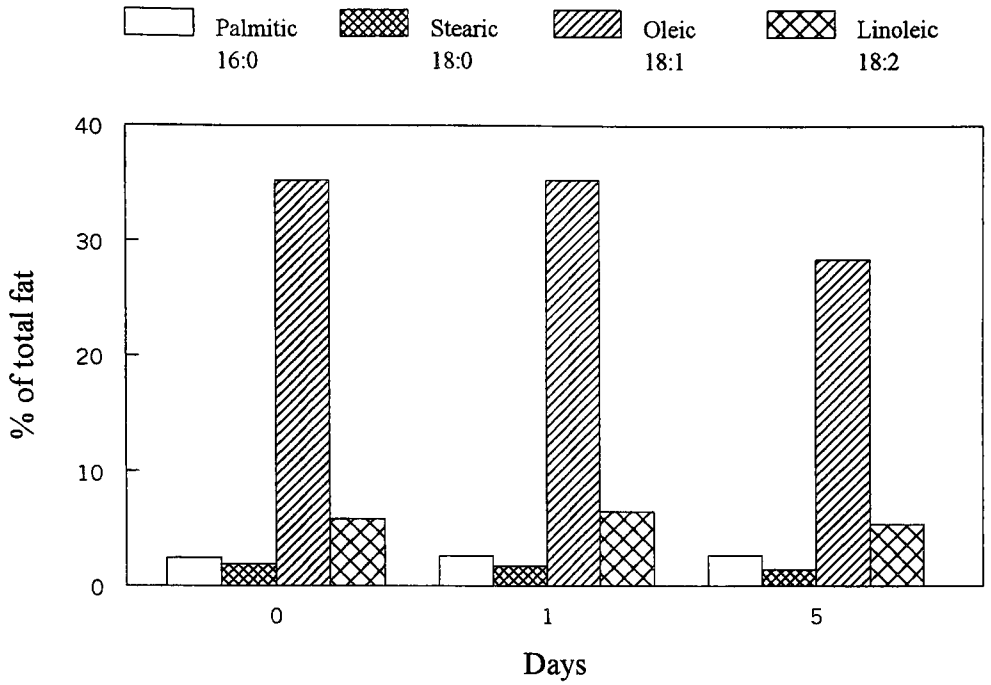

Figure 13. Fatty acid profile of canola oil on days 0, 1 and 5.

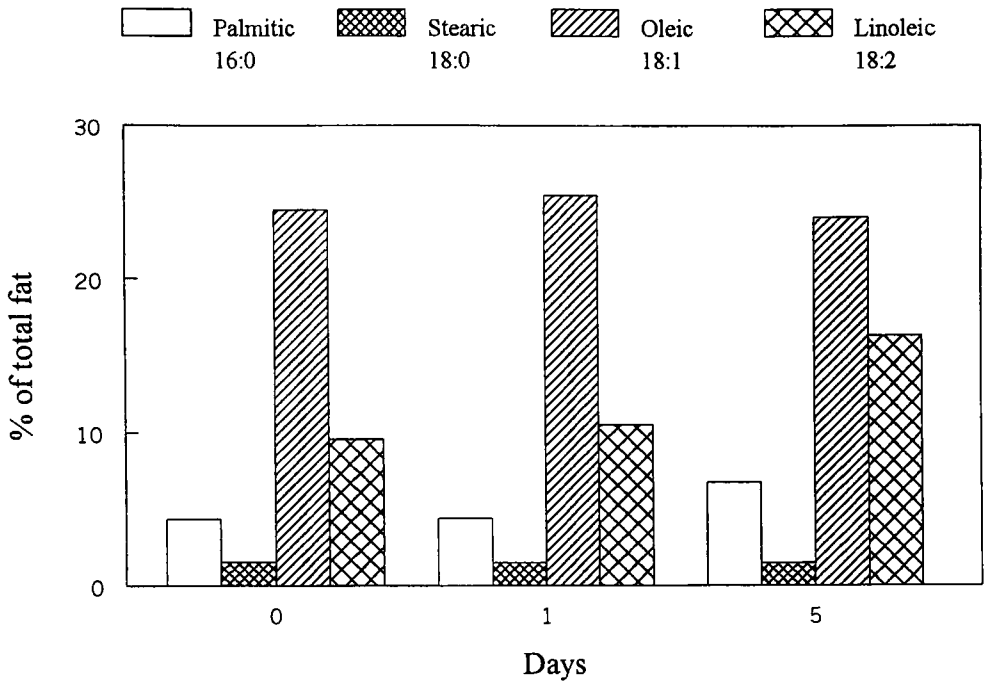

Figure 14. Fatty acid profile of soybean oil on days 0, 1 and 5.

(Xu et al. 1999). In addition, the oil from the french fries will leach into the frying oil, affecting the fatty acid profile as well.

It can be predicted from the initial fatty acid profile how oil will perform when subjected to deep-fat frying conditions. Oil that has the highest linolenic acid content will be more susceptible to degradation. Reducing the linolenic acid content will increase the oxidative stability of the frying oil (Warner and Mounts 1993).

Based on the mean of the combined trials (Table 15, Appendix A), the linolenic acid content of the three fresh oils was very low. Cottonseed oil naturally has very low levels of linolenic acid, while the hydrogenated canola oil in this study had 0.20% linolenic acid, and hydrogenated soybean oil had 0.64% linolenic acid. In both of the hydrogenated oils on day 1, linolenic acid decreased by 45% in canola oil and 7% in soybean oil. By frying day 5, linolenic acid was decreased by 87% in canola oil and 90% in soybean oil.

As expected, linoleic acid was the predominate PUFA in all of the oils, with cottonseed oil having the highest concentration (47%). In the literature, linoleic acid in cottonseed oil ranges from 33-58%. Hydrogenated canola oil and hydrogenated soybean oil contained 6% and 10% linoleic acid, respectively. Linoleic acid level in deep-fat frying oil does not appear to be a noticeably negative factor in oil stability and sensory scores of the fried food (Xu et al. 1999). In fact, the presence of some degradation products from linoleic acid enhances the deep-fat fried flavor of foods. Linoleic acid decreased in cottonseed oil by 41% on day 1 and 108% on day 5. Linoleic acid contents of both canola and soybean oil actually increased by 10% and 9%, respectively, on day 1. By day 5,

linoleic acid decreased by 8%. For soybean oil, the linoleic acid content continued to increase and was 41% higher by day 5.

Oleic acid content was more stable in the three oils than was linoleic acid. Oleic acid is a mono-unsaturated fatty acid. As level of unsaturation increases, break down increases at a faster rate. This can be attributed to the destruction of double bonds by oxidation, scission, and polymerization (Tyagi and Vasishtha 1996). On day 0 (fresh/unused) the oleic acid content of cottonseed oil, canola oil and soybean oil was 17%, 35% and 25%, respectively. On days 1 and 5, the oleic acid content of cottonseed oil and soybean oil remained very stable, only changing by 1 and 4%, respectively. Oleic acid in canola oil remained constant on day 1, and decreased by 24% on day 5. In soybean oil, oleic acid remained very constant, varying from 24%-25%.

Palmitic acid was the predominant saturated fatty acid in the three oils. Studies have shown, as frying time increases, the saturated fat content of oil will increase. Contrary to what was expected, the saturated fat content of cottonseed oil actually decreased, from 18% on day 0, to 13% on day 1 (41% decrease), to 10% on day 5 (92% decrease). There were only minor changes in the palmitic acid content of canola oil. Only a 5 and 8% increase was found in palmitic acid content of canola oil on days 1 and 5. Soybean oil followed typical patterns of frying oil in relation to the saturated fat content. The palmitic acid content in fresh soybean oil was 4%, with only a slight 1% increase on day 1. However, by frying day 5, palmitic acid increased by 36% (7%).

Stearic acid concentration was less than 2% in all three fresh oil and remained that way through day 5. Overall, the fatty acid profile of the three oils did not follow the

expected results documented in the literature. As oil degrades, there is an increase in saturated fatty acids and a decrease in unsaturated fatty acids, which is attributed to the breakdown of mono- and polyunsaturated fatty acids. In order to have produced this result in the current study, the oils would have needed to be subjected to more stress.

The french fries used in this study were par-fried in beef tallow and/or vegetable oil (partially hydrogenated soybean and/or canola oil). This is a common practice of frozen potato producers for three reasons. First, it decreases final french fry cooking time. Secondly, the french fry will cook evenly, without excessive browning on the outside and undercooking on the inside. Lastly, there will be less splattering of oil during the final cooking of the french fry. To clearly show changes within the oil itself, the french fry would have needed to be par-fried (or precooked) in water. This would eliminate oil contamination from the french fry.

Fatty acid composition of the french fries

Fat absorption by the french fries remained constant as days of frying increased. The fat content of the raw french fry was 4.1%, while the cooked french fries were an average of 11.4%. This suggests that 64% of the fat content came from the frying oil. This is more complex than it sounds, because some of the oil in the french fries may have leached out into the frying oil during the deep fat frying process, in addition to absorbing frying oil.

The fatty acid profile of the raw french fries are as follows: palmitic 15%, stearic 12%, oleic 19%, linoleic 3% and linolenic 0.3%. Figures 15, 16 and 17 show the fatty acid

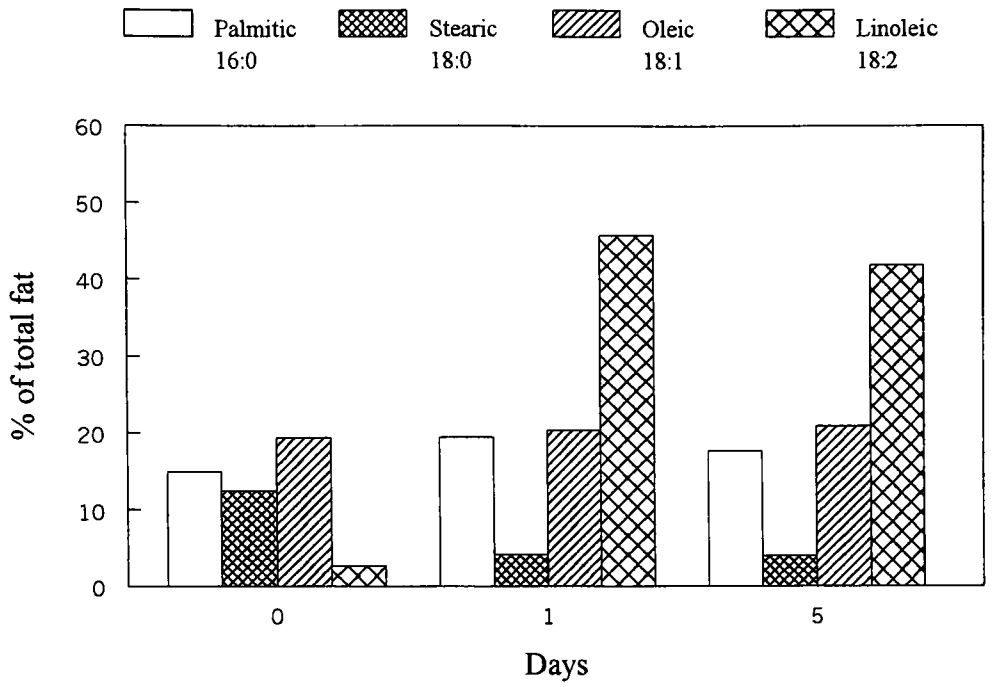

Figure 15. Fatty acid profile of french fries fried in cottonseed oil on days 0 (fresh), 1 and 5.

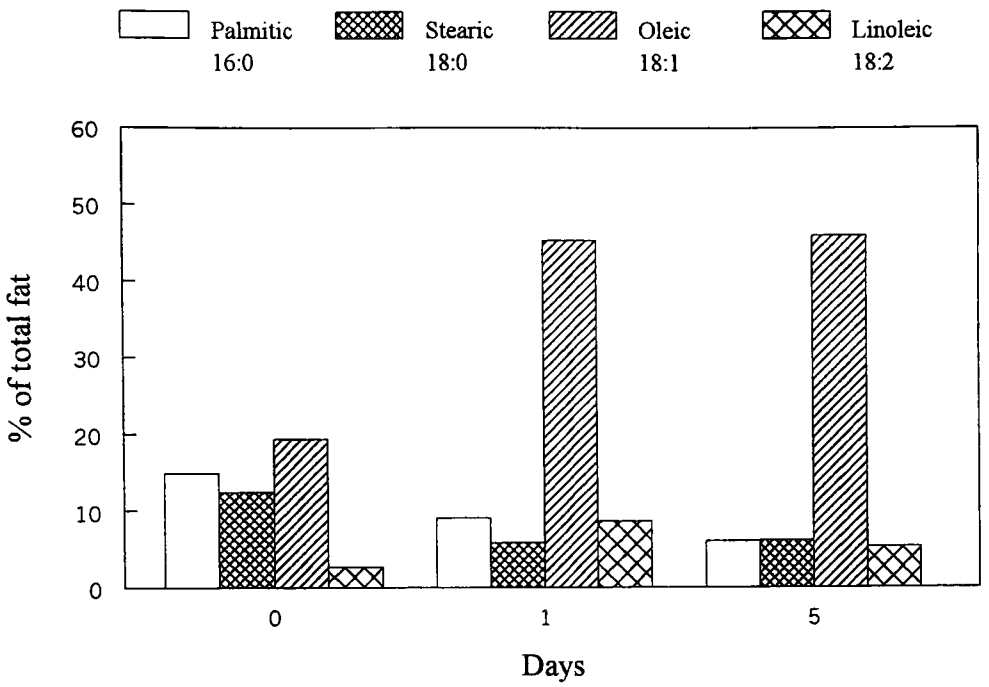

Figure 16. Fatty acid profile of french fries fried in canola oil on days 0 (fresh), 1 and 5.

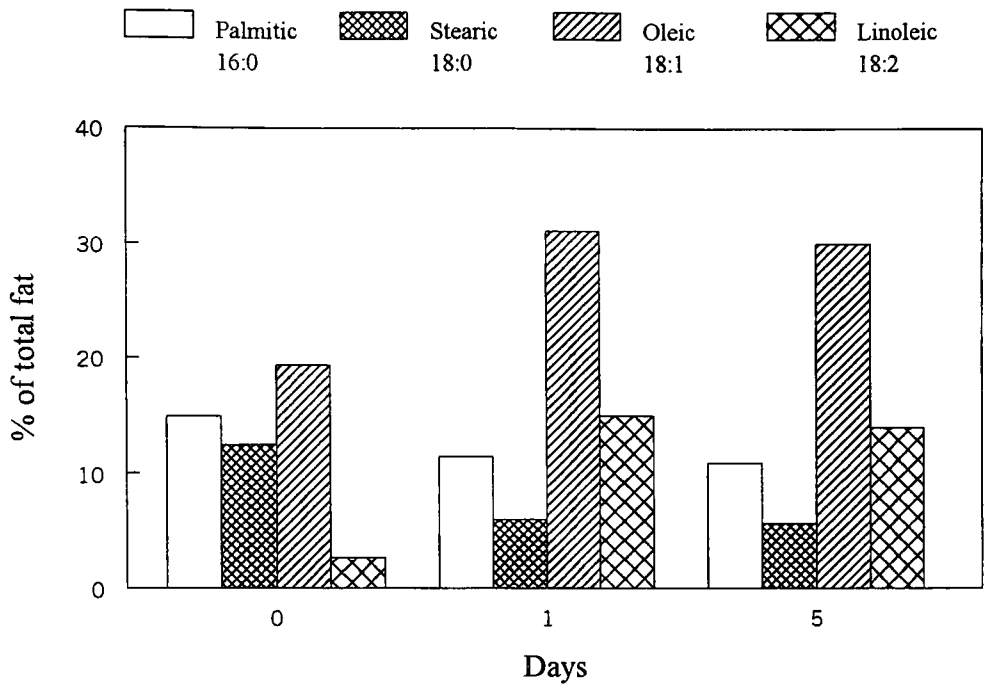

Figure 17. Fatty acid profile of french fries fried in soybean oil on days 0 (fresh), 1 and 5.

profiles of the french fries fried in cottonseed oil, canola oil and soybean oil, respectively. The largest change in the fatty acid profile occurred on the first day of frying (Table 15, Appendix A). For the remainder of the frying time (days 1-5) the profile remained fairly stable. Palmitic acid was the most abundant saturated fatty acid found in the three oils and this was also the case for the french fries. Palmitic acid increased by 25% in the french fries fried in cottonseed oil. This may be due to absorption of palmitic acid from the frying oil, since this acid actually decreased in the cottonseed oil. Palmitic acid decreased by 25% in french fries fried in soybean oil. This may have been due to leaching of the fatty acid from the french fries into the frying oil, since palmitic acid actually increased in the soybean oil. French fries fried in canola oil showed a 50% decrease in palmitic acid. However, the frying oil did not exhibit this large of an increase.

Stearic acid decreased by approximately 67% in the french fries fried in cottonseed oil, and 53% in those fried in both the canola oil and soybean oil. Stearic acid content in the three oils was less than 2% in the fresh oils and remained so through day 5 as explained in an earlier section.

Very little change was seen in oleic acid content of french fries fried in cottonseed oil, or cottonseed oil. However, Oleic acid increased by 137% in french fries fried in canola oil and 58% in french fries fried in soybean oil. A 25% decrease was seen in the oleic acid content of canola oil, however, like cottonseed oil, the oleic acid content of soybean oil remained relatively stable.

For the cottonseed oil french fries, the largest change was seen in linoleic acid. This fatty acid started out at 2.6% in the raw french fry, and increased to 43.84%

(averaged for days 1 and 5). Cottonseed oil contains approximately 47% linoleic acid. Linoleic acid decreased in cottonseed oil on both days 1 and 5. The fact that the french fries absorbed a significant amount of this fatty acid explains some of the decrease. In addition, some of the decrease in the linoleic content of the cottonseed oil may have been due to degradation. On average, the linoleic acid content of canola oil french fries and soybean oil french fries increased slightly to 6.9% and 14.5%, respectively. The linoleic acid content of both oils was very similar to the linoleic acid content of the french fries cooked in those oils. The linolenic acid content in the raw french fries and the cooked french fries fried in all three oils was less than 1%.

Trans fatty acid content of the oil and french fries

The trans fatty acid content of cottonseed oil was significantly lower than the other two oils (Figure 18). There was no significant effect of days of frying on trans fatty acid content. The initial trans fatty acid content of fresh cottonseed oil, canola oil and soybean oil was 0.1%, 30.1% and 19.1%, respectively. The trans fatty acid content of canola oil actually declined on day 1 to 21.30% and leveled off to 21.17% on day 5. Soybean oil had a very stable trans fatty acid content of approximately 20% on days 1 and 5 (Table 15, Appendix A).

The trans fatty acid content of the pre-fried, raw french fries ranged from 8%-59% (average 30.3%). This is a very large variation, and according to the lab that analyzed this data, it was very difficult to extract enough fat to perform the test to detect trans fatty acids. Filary (1999) found a trans fatty acid content of 1.3%, but only one sample was

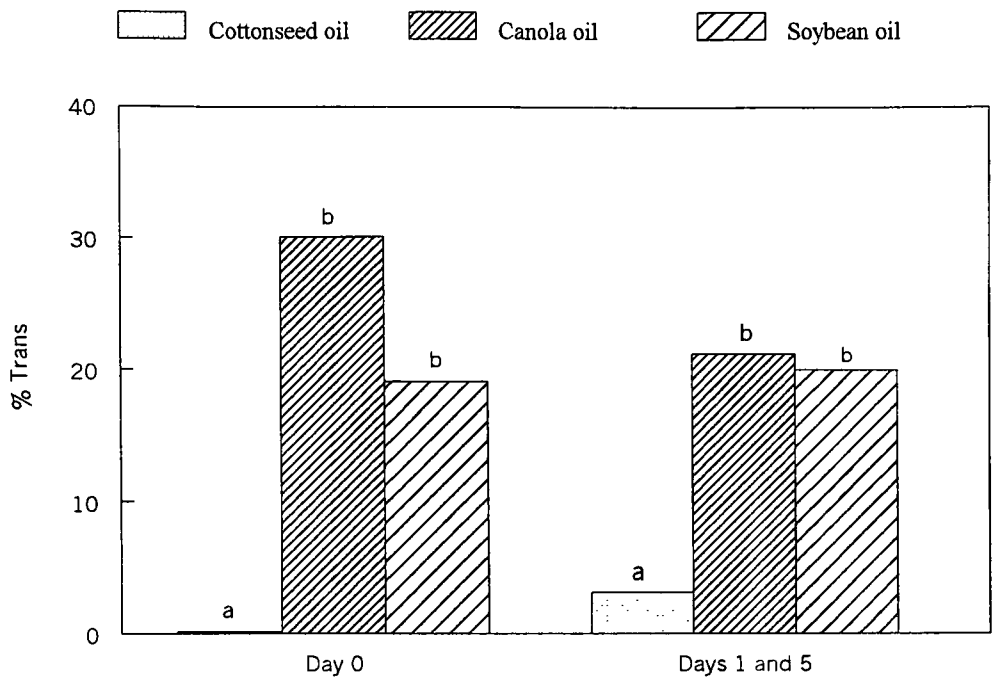

Figure 18. Trans fatty acid content of cottonseed oil, canola oil, and soybean oil on day 0 (fresh) and days 1 and 5 (combined).

analyzed. The trans fatty content of the french fries cooked in cottonseed oil (4.54%) were significantly lower than for canola oil (20.05%) and soybean oil (21.30%) (Figure 19). There was no significant effect of days of frying on trans fatty acid content of the french fries. These means were very similar to the trans fatty acid content found in the frying oil.

According to research on trans fatty acids and their effect on health, gram for gram, trans fatty acids may be associated with greater health risk than saturated fatty acids. Trans fatty acids have been shown to not only increase LDL-cholesterol levels, but to reduce HDL-cholesterol levels as well. Saturated fatty acids have been shown to reduce LDL-cholesterol levels, but they have no effect on HDL-cholesterol levels. French fries fried in cottonseed oil were higher in saturated fatty acids and lower in trans fatty acids compared to french fries fried in the other two oils. Currently, trans fatty acids are not added to the saturated fatty acid content on a food label. If trans and saturated fatty acids are added together, french fries fried in cottonseed, canola and soybean oil contain 30%, 36% and 41%, respectively, using data obtained on day 5 (Table 16, Appendix A). French fries fried in cottonseed oil still have a lower combined total of saturated and trans fatty acids, and more importantly the percentage of the total contributed by trans fatty acids is lower. The percentage of the total contributed by trans fatty acids is 9%, 53% and 55% for cottonseed, canola and soybean oil, respectively. If trans fatty acids, gram for gram are more dislipidemic than saturated fatty acids, it would be wiser to choose an oil with a lower content of trans fatty acids, even if it was higher in saturated fatty acids.

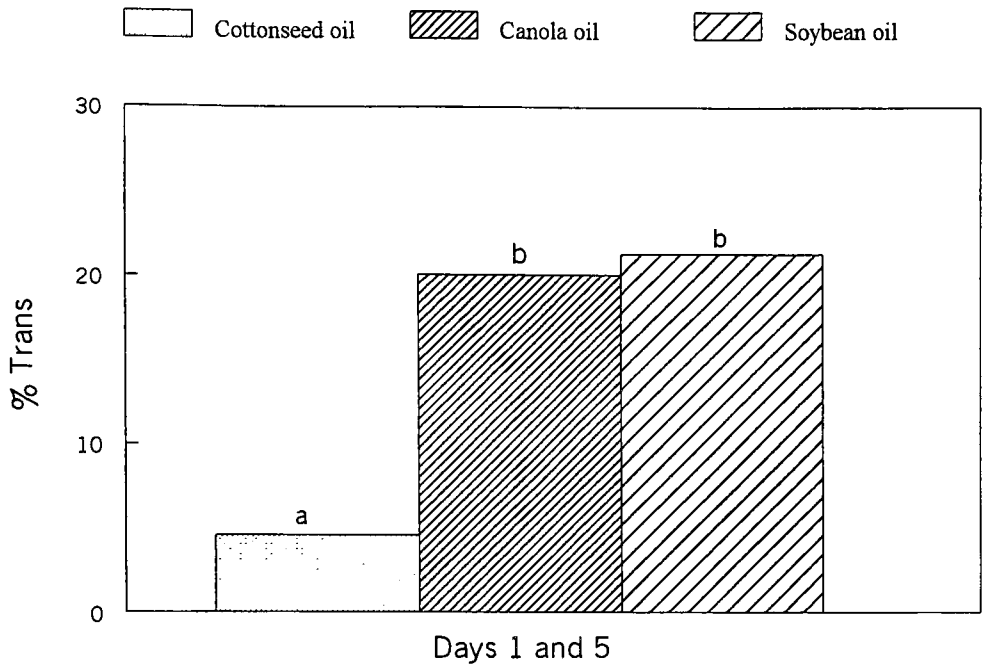

Figure 19. Trans fatty acid content of french fries fried in cottonseed oil, canola oil, and soybean oil on days 1 and 5 (combined).

In terms of mono- and poly-unsaturated fatty acids and their effect on health, studies have shown that mono-unsaturated fatty acids may reduce only LDL-cholesterol levels, and have no effect on HDL-cholesterol levels. Poly-unsaturated fatty acids are reported to lower both LDL- and HDL-cholesterol levels. French fries fried in both canola and soybean oil had higher MUFA levels than those fried in cottonseed oil. Cottonseed oil is higher in PUFA levels. More studies need to be done on the effects of the fatty acid profile on health.

CHAPTER V

CONCLUSION

The purposes of this research study were to determine if unhydrogenated cottonseed oil was suitable for the deep-fat frying process and to determine the nutritional characteristics and quality of cottonseed oil and the french fries cooked in the oil. Hydrogenated canola oil and hydrogenated soybean oil were used for comparison. Blumenthal (1991) stated that all triglyceride-based frying oils have the same characteristics in terms of how much abuse they can withstand before becoming unfit for producing high quality foods. This research found that cottonseed oil, hydrogenated canola oil and hydrogenated soybean oil were comparable in terms of their stability characteristics under the conditions used in this study. The food service industry is hard on frying oil due to the constant fluctuation in temperature. Temperature extremes cause oil to degrade at a faster rate than oils heated continuously, with little fluctuation in temperature (Perkins and Van Akkeren 1965). To effectively evaluate degradation, more food product would need to be fried than what was achieved in this study.

There were no significant differences in oil absorption for all three oils as determined by laboratory and physical measurements. French fries contained approximately 11% fat, an increase of 140% from the raw product.

Research has shown that trans fatty acids can have detrimental effects on health. Studies have shown that trans fatty acids not only increase LDL-cholesterol levels, they decrease HDL-cholesterol levels as well. Trans fatty acids are considered more detrimental

to blood lipid levels than saturated fatty acids due to this fact. Since fried foods contribute a large proportion of trans fatty acids consumed in the US, it is advisable to reduce the content of trans fatty acids in the frying oil. Hydrogenation contributes 75% of the trans fatty acids found in food products. Cottonseed oil can be used in its unhydrogenated state. This will become especially important when the trans fatty acid content is required to be disclosed on a food label. Fast food chains such as McDonald's are attempting to develop new frying oils that will have less trans fatty acids and more polyunsaturated fatty acids. Cottonseed oil fits this profile. It is unknown how much saturated fatty acid it takes to offset the health benefits of using a product with a decreased amount of trans fatty acids. Epidemiological studies would need to be performed to determine the health benefits of using oil with higher saturated fat content but lower trans fat content.

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APPENDIX A

TABLES

Table 7. Mean oil loss for cottonseed oil, canola oil, and soybean oil (combined) on days 1-5.

Days	Mean (kg/day)	Standard Error
1	0.92^{a}	0.004
2	0.70^{b}	0.004
3	0.78^{b}	0.004
4	0.70^{b}	0.004
5	0.77^{b}	0.004

^{a,b}Means within a column with different superscripts are significantly different ($P<0.05$) n=132

Table 8. Mean differences in french fry cooking loss among tanks 1-3 for cottonseed oil, canola oil, and soybean oil (combined).

	Combined oil (kg/day)	
Tanks	Mean	Std Error[1]
Left outside	0.627[a]	0.006
Middle	0.662[b]	0.006
Right outside	0.639[c]	0.006

[a,b,c] Means within a column with different superscripts are significantly different ($P<0.05$)
[1]Std. Error = Standard Error
n=807

Table 9. Mean french fry cooking loss for cottonseed oil, canola oil, and soybean oil (combined) on days 1-5.

Days	Mean (kg)	Standard Error
1	0.657[a]	0.03
2	0.654[a]	0.03
3	0.644[a]	0.03
4	0.636[ab]	0.03
5	0.623[b]	0.03

[a,b]Means within a column with different superscripts are significantly different ($P<0.05$)
n=807

Table 10. Mean peroxide values (meq peroxide/kg) of cottonseed oil, canola oil, and soybean oil on days 1-5.

	Cottonseed oil		Canola Oil		Soybean Oil	
Days	Mean	Std Error[3]	Mean	Std Error[3]	Mean	Std Error[3]
1	2.04^{am}	0.078	1.24^{bm}	0.026	1.51^{bm}	0.044
2	1.91^{amn}	0.060	1.61^{bmn}	0.056	1.61^{bmm}	0.046
3	2.69^{amn}	0.082	1.20^{bmn}	0.049	1.59^{bmn}	0.075
4	2.94^{amn}	0.053	1.58^{bmn}	0.047	1.56^{bmn}	0.038
5	2.85^{an}	0.088	1.56^{bn}	0.039	1.84^{bn}	0.056

[1]Means with the same letter were not significantly different at the alpha = 0.05 level.
[2]The letters 'a' and 'b' denote significant differences between oil types at each frying day and the letters from 'm' and 'n' denote differences due to the effect of frying day.
[3]Std Error = Standard Error
n=131

Table 11. Mean iodine values (g halogen/100 g fat) of cottonseed oil, canola oil, and soybean oil in tanks 1-3.

	Cottonseed Oil		Canola Oil		Soybean Oil	
Tank	Mean	Std Error[3]	Mean	Std Error[3]	Mean	Std Error[3]
1	120.03^{amn}	10.18	$84.75^{bmn,}$	9.74	93.30^{cmn}	10.18
2	135.57^{am}	10.18	83.73^{bm}	9.74	98.60^{cm}	9.74
3	108.43^{an}	9.74	86.59^{bn}	10.18	95.43^{cn}	9.74

[1]Means with the same letter were not significantly different at the alpha = 0.05 level.
[2]The letters 'a' and 'b' denote significant differences between oil types at each frying day and the letters from 'm' and 'n' denote differences due to the effect of the tank.
[3]Std Error = Standard Error
n=131

Table 12. Mean free fatty acid values (%oleic) of cottonseed oil, canola oil, and soybean oil on days 1-5.

Day	Mean	Standard Error
1	0.079[a]	0.022
2	0.116[ab]	0.022
3	0.148[bc]	0.022
4	0.224[d]	0.024
5	0.256[d]	0.024

[1]Means with the same letter were not significantly different at the alpha = 0.05 level.
[2]The letters from 'a' and 'd' denote significant differences due to the effect of frying day.
n=131

Table 13. Mean p-anisidine values of cottonseed oil, canola oil, and soybean oil on days 1-5.

	Cottonseed Oil		Canola Oil		Soybean Oil	
Day	Mean	Std Error[3]	Mean	Std Error[3]	Mean	Std Error[3]
1	15.50^{am}	0.255	6.73^{bm}	0.132	9.65^{bm}	0.187
2	19.68^{an}	0.524	11.52^{bn}	0.088	15.56^{bn}	0.171
3	26.37^{ao}	0.807	16.36^{bo}	0.199	17.94^{bo}	0.401
4	25.62^{ao}	1.431	17.42^{bo}	0.300	18.91^{bo}	0.565
5	26.96^{ap}	0.679	19.95^{bp}	0.147	25.25^{ap}	0.396

[1]Means with the same letter were not significantly different at the alpha = 0.05 level.
[2]The letters 'a' and 'b' denote significant differences between oil types at each frying day and the letters from 'm' and 'p' denote differences due to the effect of the day.
[3]Std Error = Standard Error
n=86

Table 14. Mean totox values of cottonseed oil, canola oil, and soybean oil on days 1-5.

	Cottonseed Oil		Canola Oil		Soybean Oil	
Day	Mean	Std Error[3]	Mean	Std Error[3]	Mean	Std Error[3]
1	18.58^{am}	0.327	9.41^{bm}	0.163	12.49^{bm}	0.273
2	23.44^{an}	0.523	15.12^{bn}	0.132	19.28^{bn}	0.238
3	31.55^{ao}	0.889	19.20^{bo}	0.237	21.68^{bo}	0.533
4	30.28^{ao}	1.499	21.06^{bo}	0.373	21.23^{bo}	0.660
5	33.28^{ap}	0.628	23.39^{bp}	0.099	29.13^{ap}	0.495

[1]Means with the same letter were not significantly different at the alpha = 0.05 level.
[2]The letters 'a' and 'b' denote significant differences between oil types at each frying day and the letters from 'm' and 'p' denote differences due to the effect of the day.
[3]Std Error = Standard Error
n=86

Table 15. Composition of cottonseed oil, canola oil, and soybean oil on days 0, 1 and 5.

Fatty acids	Cottonseed oil (days)			Canola oil (days)			Soybean oil (days)		
(wt/%)	0	1	5	0	1	5	0	1	5
16:0	18.35	12.98	9.55	2.43	2.58	2.66	4.34	4.38	6.75
18:0	1.47	1.10	1.23	1.86	1.68	1.43	1.54	1.49	1.47
18:1	16.65	13.05	13.64	35.27	35.31	28.48	24.51	25.44	24.05
18:2	46.75	33.17	22.52	5.80	6.44	5.37	9.56	10.53	16.32
18:3	0	0	0	0.20	0.13	0.07	0.64	0.60	0.22
Saturated	24.36	24.07	23.50	9.35	9.23	10.73	14.48	13.68	16.31
MUFA	19.68	21.57	29.36	78.03	77.15	75.18	60.43	60.85	52.78
PUFA	55.96	54.36	47.15	12.62	13.62	14.10	25.09	25.47	30.90
Trans	0.10	1.20	4.97	30.1	21.30	21.17	19.1	20.00	20.10

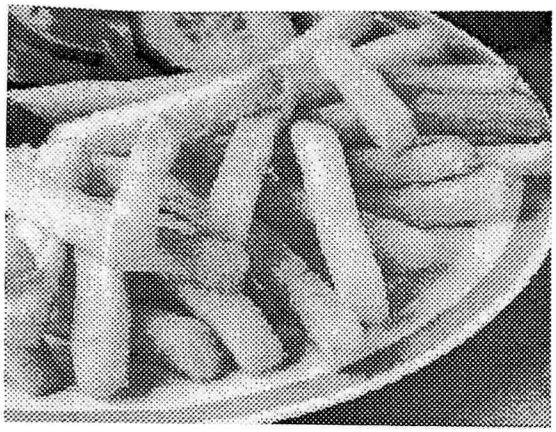
Table 16. Composition of french fries fried in cottonseed oil, canola oil, and soybean oil on days 0, 1 and 5.

Fatty acids	Raw french fries (day)	Cottonseed oil (days)		Canola oil (days)		Soybean oil (days)	
(wt/%)	0	1	5	1	5	1	5
16:0	14.89	19.4	17.66	9.02	6.03	11.40	10.86
18:0	12.39	4.13	3.97	5.77	6.07	6.00	5.63
18:1	19.31	20.27	20.89	45.98	45.27	31.12	30.02
18:2	2.63	45.78	41.89	8.57	5.30	15.00	13.99
18:3	0.334	0.30	0.29	0.35	0.41	0.93	0.74
Saturated	32.39	25.68	23.56	17.49	14.23	19.93	18.53
MUFA	50.86	22.82	27.35	62.33	63.46	47.61	49.01
PUFA	5.81	46.95	43.42	13.31	10.02	19.90	18.51
Trans	33.11	2.62	6.77	19.69	21.94	20.11	22.64
Trans + Saturated	65.50	28.30	30.33	37.18	36.17	40.04	41.17
% Trans	51	9	22	53	61	50	55

APPENDIX B

FRENCH FRY SPECIFICATION SHEET

Payette Farms Regulars



UPC: 7117922101

Product Code: 2210159B

Packaging: Case Pack -- 6/5#
Net Weight -- 30.0 lbs.
Gross Weight -- 32.0 lbs.
Cube -- 1.270

Product Benefits:

- Meets USDA grade "A" quality standards.
- Exceeds USDA line flow spec.
- Higher moisture content--texture will not hold like higher-quality fries.
- Available in all popular cuts.
- Priced low for the buyer looking for the least expensive product.

Preparation:

- For best results, deep fry 1 1/2 pounds at 350°F for 4 1/4 minutes

Specifications:

- 3/8" x 3/8" straight cut

Ingredients: Potatoes, beef tallow and/or vegetable shortening (partially hydrogenated soybean and/or canola oil), dextrose, disodium dihydrogen pyrophosphate (to maintain natural color).

Menu Solutions:

We're On Your Side®

Nutrition Facts		Amount/Serving	% Daily Value	Amount/Serving	% Daily Value
Serving Size:	3 oz (85g) frzn	**Total Fat** 4g	6%	**Total Carbohydrates** 18g	6%
		Saturated Fat 1g	5%	Dietary Fiber 2g	9%
Calories:	120	**Cholesterol** 0mg	0%	Sugars 0g	
Calories From Fat:	35	**Sodium** 15mg	1%	**Protein** 2g	
		Vitamin A	0%	Vitamin C	12%
		Calcium	0%	Iron	2%

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