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The Utilization of Fractionated
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THE UTILIZATION OF FRACTIONATED BEEF TALLOW IN FOOD SYSTEMS

By

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ABSTRACT

THE UTILIZATION OF FRACTIONATED BEEF TALLOW IN FOOD SYSTEMS

By

Susan Beth Dillery

Animal fats have traditionally been used in shortening preparations. Now, with increasing cost of vegetable oils, the functionality and utilization of tallow for use in other products is being investigated. The fractional crystallization process has shown promise as a means of increasing the utilization of tallow. Doughnuts and batter coated chicken wings were fried in original tallow, two olein fractions obtained by fractionation and a commercial soybean oil. Analysis of the physical, chemical and sensory characteristics of the products and oil revealed that the original tallow and both tallow fractions compared favorably with the control. Flavor was found to be significantly higher for all products when compared to the control. White layer cakes were prepared utilizing original tallow, a solid and an olein fraction, and a commercial shortening and an emulsifier. Analysis of the physical and sensory characteristics of the products revealed that the cakes prepared with original tallow and both tallow fractions compared favorably with the control cake.

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INTRODUCTION

Animal fats, tallow and lard, have traditionally been used in shortening preparations. More recently, hydrogenated vegetable oils have claimed a greater share of this market. The steadily increasing cost of vegetable oils and imported fats and oils such as cocoa butter, palm oil, coconut oil and palm kernal oil prompts the investigation of using tallow or fractionated tallow as potential replacements for these more expensive fats.

The fractionation of tallow produces products with a wider range of use. Three definite uses for fractionated beef tallow have been found, the olein fraction as salad/cooking oils, the solids for shortening applications and margarine formulations and the semisolid fraction as a cocoa butter substitute and/or extender (Luddy *et al*., 1973).

Both solvent fractionated and aqueous (detergent) fractionated beef tallow have been found to be acceptable (Taylor *et al*., 1976). The aqueous fractional crystallization is preferred due to the high cost of recovering the solvent in the solvent fractionation method and the need for flame proof and explosion proof equipment.

Used oils produce poorer quality foods on frying, the poor quality being partly due to the higher fat content, off flavors, irregular browning, and poor appearance (Artman, 1969). Degradation of frying oils is measured by darkening of color of the oil, increased viscosity and the formation of oxidation products. A variety of factors can influence the degradation of an oil including type of fat used for frying, care of the frying fat, kettle design, substrate being fried and the use of antioxidants.

The purpose of this investigation was to compare the functionality and utilization of original beef tallow, various fractions obtained by aqueous fractionation of tallow and a commercial control fat in food systems. Phases 1 and 2 of this investigation utilized the 20^{o}C and 30^{o}C olein fractions, original tallow, and a commercial soybean oil in the frying of doughnuts and batter coated chicken wings, respectively. Phase 3 compared the 25^{o}C solid fraction, 35^{o}C olein fraction, original tallow and a commercial shortening in the preparation of white layer cakes.

LITERATURE REVIEW

Tallow

Current Trends in Tallow Production

The U.S. consumption of total food fats has increased steadily since 1950, with a particular increase in the vegetable oils and a decrease in animal fats (Figure 1) (Taylor *et al*., 1976; FOS, July 1980). Both visible and invisible forms of fat have increased in the diet. Salad and cooking oils have led the increase in visible fat consumption, while increased meat consumption has raised the total amount of invisible fat consumption. The increase in the use of cooking oils reflects increased direct use of edible oils by the consumer, along with growing use of vegetable oils in commercial frying, roasting, and production of prepared foods. An important development in the use of cooking oils has been in the rapid growth of the fast food restaurants in the past decade (Kromer, 1980).

Animal fats, tallow and lard, have traditionally been used in shortening preparations. Now, the use of hydrogenated all vegetable shortenings is causing a shift away from these animal fats (Kromer, 1980). The steadily increasing cost of these vegetable oils and imported fats

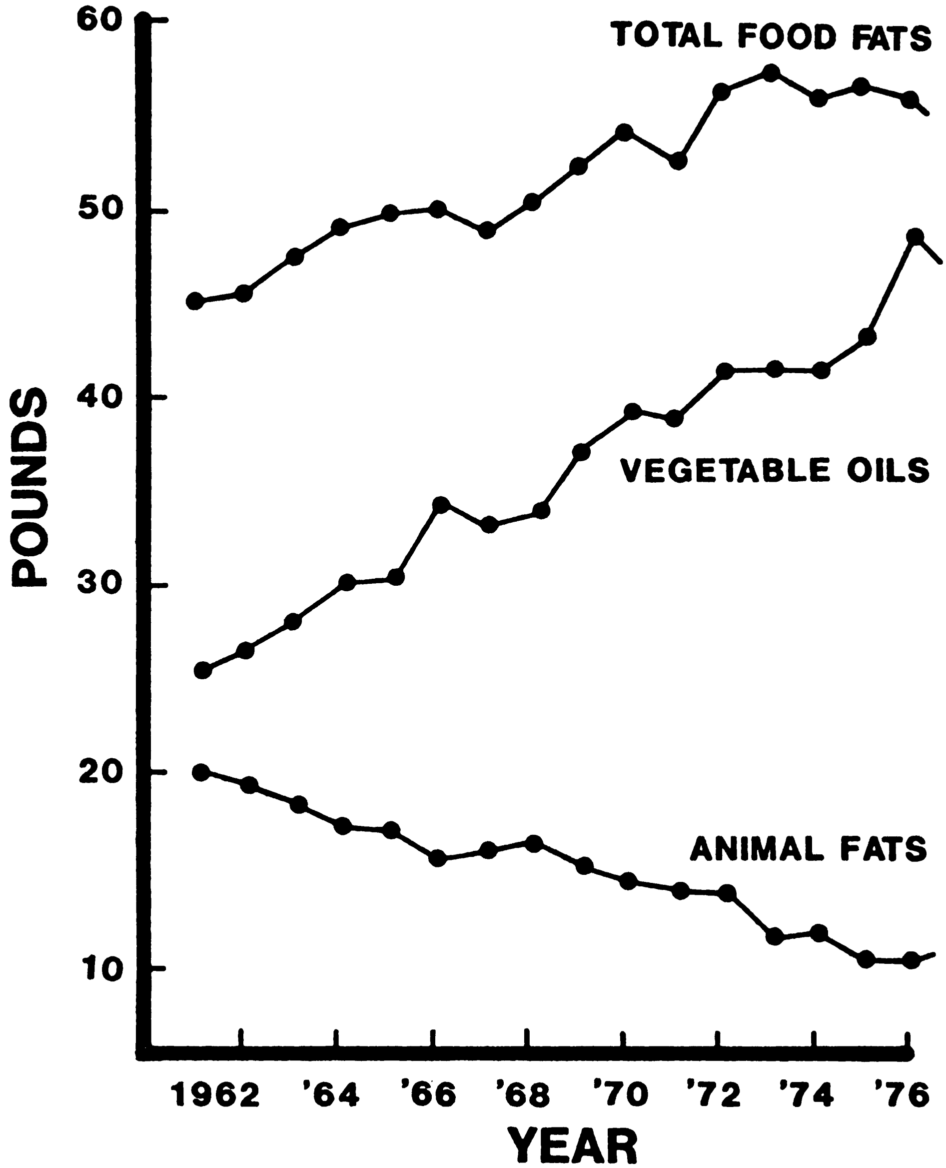


Figure 1. U.S. per capita consumption of total food fats, vegetable oils and animal fats, 1960-1977 (USDA, 1977).

and oils such as cocoa butter, palm oil, coconut oil and palm kernel oil prompts the investigation of using tallow or fractionated tallow as replacements for these more expensive fats.

The use of tallow has been primarily limited to inedible sources such as lubricants, soaps, feeds and fatty acid production (Taylor et al., 1976). Edible tallow has been primarily used as commercial and institutional shortening products (FOS, Oct. 1981). If a market could be found for tallow and tallow products, much of what is classified as inedible could be edible tallow which claims a higher price (Luddy et al., 1973).

Over the past decade a tremendous increase has taken place in edible tallow production while only marginal gains were made in total tallow production (Figure 2). Total tallow production has remained relatively stable at 7.0 billion pounds per year since 1976 (Anon., 1978; FOS, Oct. 1981). Luddy et al. (1973) postulated that increased beef production could increase the total tallow production to 7.0 billion pounds per year by 1980. Beef production has not increased but decreased. Even though fewer cattle were slaughtered, the carcass weight was heavier, thus the goal of 7.0 billion pounds per year was attained (FOS, 1981). During this same time, the production of edible tallow increased over 200% (Figure 3). This increase can be felt both in domestic use and exports, with a greater

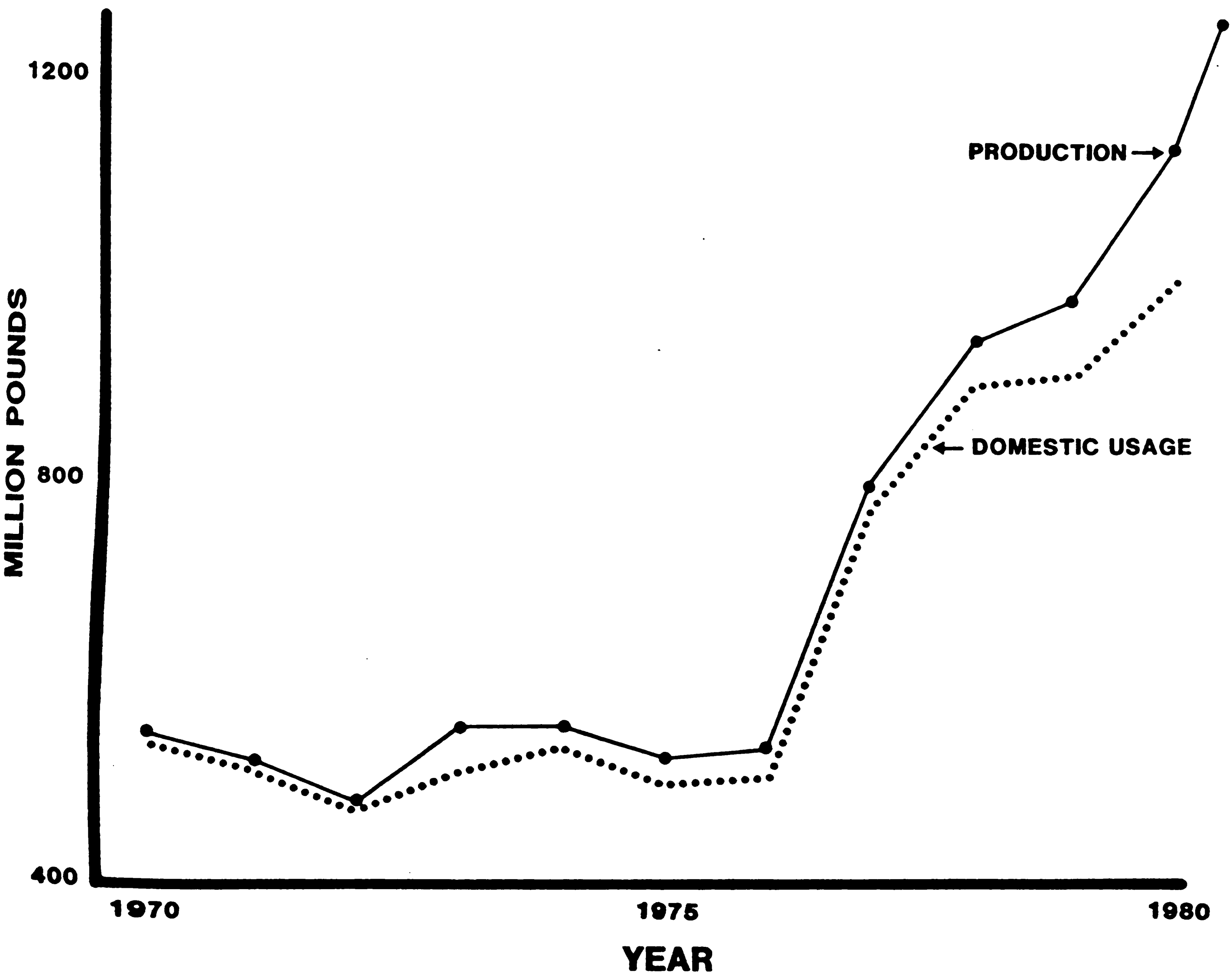


Figure 2. Edible tallow production and domestic usage 1970-1981.

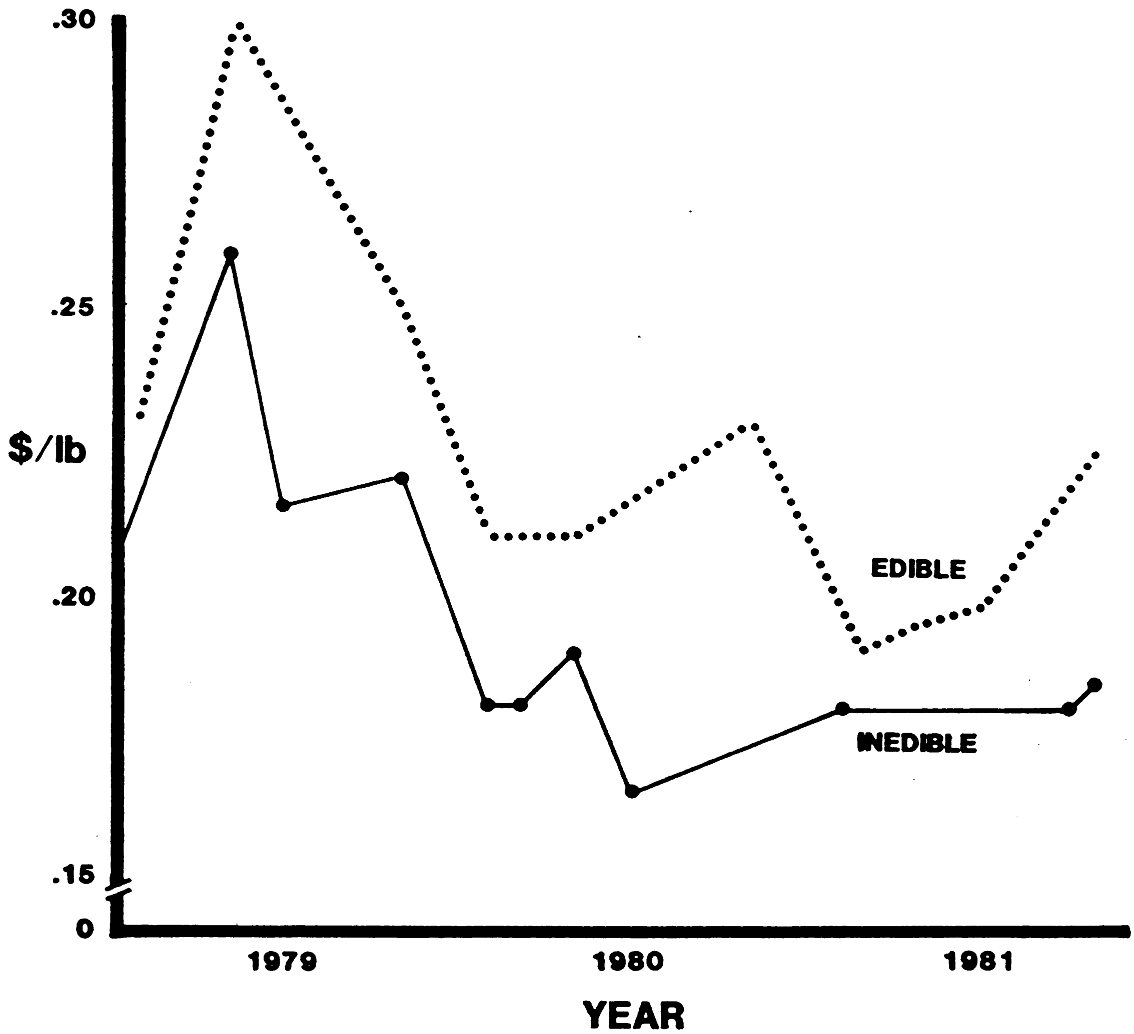


Figure 3. Inedible and edible tallow prices 1979-1981.

percentage of the production staying at home. A 10% increase in the domestic use of edible tallow was seen from 1979/80 to 1980/81 (FOS, Oct. 1981).

As indicated in Figure 3, prices of both edible and inedible tallow have fluctuated over the past three years. The decrease in price, and therefore demand, in early 1980 can be attributed to record world supplies of competitive fats and oils and suspension of export shipments to the USSR (FOS, Feb. 1980). Economic recession has also suppressed tallow prices. Tallow has been used extensively in the manufacture of durable goods by the housing and auto industries which have been severely effected by economic recession (FOS, July 1980). A brighter future for tallow will be seen due to an increase in petrochemical food stocks which may increase the demand for tallow and send prices up (FOS, Oct. 1979; Feb. 1980).

The large increase in production of edible tallow can be attributed, in part, to changes in the meat packing industry. Originally, carcasses were cut at the retail location into "retail-cuts" with fat trimmings going to inedible sources. Now, with centralized packing, under Federal inspection, the same fat trimmings are classified as edible tallow (FOS, Oct. 1981). Thus, the increased production needed for increased marketability can be achieved.

Fractionation of Tallow

Early fractionation of beef tallow was used primarily to yield pure glyceride fractions by solvent (acetone) crystallization (Brown, 1941). Solvent fractionation was also used to determine the glyceride composition of various fractions in response to temperatures (Riemenschneider et al., 1946). Several disadvantages are found in solvent fractionation; the cost of recovering the solvents is high and the equipment must be flame proof and explosion proof. Dry fractionation has also been attempted but at low temperatures or when small crystals are formed, filtration is virtually impossible.

Aqueous fractionation of beef tallow has the advantages of the solvent method with none of the disadvantages. A surface active agent, sodium dodecyl sulfate (SDS), and water containing an inorganic salt (Na_2SO_4) with a partially crystallized oil determines a temperature dependent fraction. Rek (1977) developed this procedure and it has been used in the fractionation of palm oil (Haraldson, 1974). Bussy and co-workers (1981) perfected this procedure for use with beef tallow. The method of choice utilized the incorporation of SDS as a powder into the softened tallow at 40^{o}C. The SDS tallow mixture was allowed to crystallize for 18 hours, than an aqueous solution of sodium sulfate (Na_2SO_4) was added and dispersed for one hour. Centrifugation followed with the ensuing separation of the olein and solid fractions. A decrease in temperature with no additional detergent, along with centrifugation, produced further fractions (Figure 4).

A commercial procedure has been developed for large scale continuous fractional crystallization. In 1974, Haraldson delivered a paper at the Palm Oil Symposium in which he described this procedure, developed by the Alfa-Laval Company. The lipofrac procedure was developed about 1964 and has been used extensively for the aqueous fractionation of beef tallow in Australia. This process has also found success in fractionating palm oil. In 1974, 21 of the 25 plants operating were used for the fractional crystallization of beef tallow.

Functionality of Tallow in Food Systems

The functionality of beef tallow in a variety of food systems has been investigated. Early work by Morris *et al*. (1956) looked at the use of original tallow, rearranged tallow, hydrogenated tallow, and tallow-vegetable blends for shortening applications. These tallow blends compared reasonably well with standard all vegetable shortenings and with slight hydrogenation and incorporation of antioxidants, flavor reversion was not significant. More recent use of beef tallow in shortening applications was performed by Bundy and coworkers (1981). In this investigation, solid and olein tallow fractions were used with and without

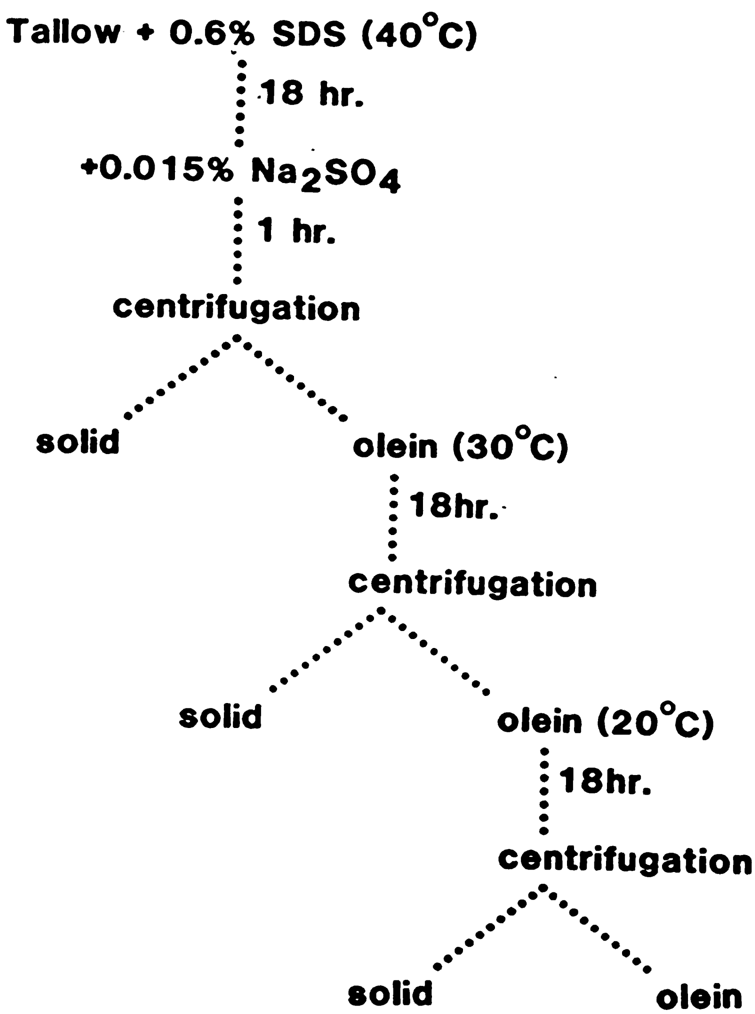


Figure 4. An aqueous fractional crystallization scheme of beef tallow (Bussey _et al_., 1981).

emulsifier in the preparation of white layer cakes. It was found that optimum products could be prepared using solid ($25^{o}C$) tallow fraction with an emulsifier present. Hoerr (1960) found that tallow forms a very stable β' crystal even after again during normal storage. With storage under unusual conditions the β' form polymorph did not form. Moncrieff (1970) confirmed that for a shortening to perform satisfactorily it must be in the β-stable polymorphic form.

Holsinger et al. (1978) found solvent fractionated tallow to be acceptable as the fat component in a whey-soy nutritious beverage mix. In this experiment, the whey-soy mix, both fortified and unfortified, were stored at $37^{o}C$. After storage for 6 months, no significant differences in flavor were found between the tallow samples and the control soybean oil samples. In addition, beef tallow oils were less susceptible to oxidative changes than soybean oils as determined by peroxide values. Thus, beef tallow shows promise in food systems when enhanced oxidative stability is desired.

Luddy et al. (1973) and Taylor et al. (1976) have reported on the use of a semi-solid tallow fraction as a cocoa butter extender and/or substitute. Luddy et al. (1973) investigated the acetone crystallization procedure. This procedure yielded five fractions; two solid fractions useful in shortening and margarine formulations, two liquid fractions having possible functions as salad and cooking oils, and a semi solid fraction (no. 4) with similarities to cocoa butter. The semi-solid "cocoa butter" fraction corresponds in glyceride composition and melting point curves to cocoa butter. By blending increments of a solid fraction (no. 3) with the semi solid fraction (no. 4) the melting point range can be raised thus increasing the applications of tallow by use as a confectionary coating.

DeFouw *et al*. (1981) investigated the use of detergent (aqueous) fractionated beef tallow oils and tallow oils in combination with soybean and corn oils as a deep-fat frying medium for french fries. Results of this investigation led to the use of tallow oils in deep-fat frying operations due to the physical stability of the oils and panelists acceptance of the fried product.

Use of Tallow Fractions

Three definite uses for fractionated beef tallow have been found, the olein fraction as salad/cooking oils, the solids for shortening applications and margarine formulations and the semi-solid fraction as a cocoa butter extender and/or substitute. Both solvent fractionated and aqueous (detergent) fractionated beef tallow have been found to be acceptable.

Deep Fat Frying

Changes in Frying Fats

During normal commercial deep-fat frying, the oil is subjected to repeated elevated temperatures usually in the presence of oxygen. These conditions can cause chemical degradation of the oil, producing a product of decreased quality. Chemical degradation can be hydrolysis, oxidation, and thermally induced polymerization. Oxidation of the oils is the chief concern in commercial deep fat frying, although with increased abuse, thermal polymerization could also possibly occur (Perkins, 1960).

Oxidation. Oxidative rancidity can take the form of autoxidation or thermal oxidation. Autoxidation has been defined as the oxidation of a fat or an oil at temperatures up to 100^{o}C, while thermal oxidation is the oxidation at approximately 200^{o}C in the presence of air or with aeration (Perkins, 1960). In more general terms, thermal oxidation is related to a condition seen in thermally abused fata and oils with autoxidation as the condition referred to in the normal process of storage and deep fat frying.

Oxidized fats are those commonly referred to as rancid with a characteristic flavor and odor. In most societies, this flavor and odor change is thought of as undesirable and the related food spoiled. In some parts of the world where refrigeration is not common place, a product may be

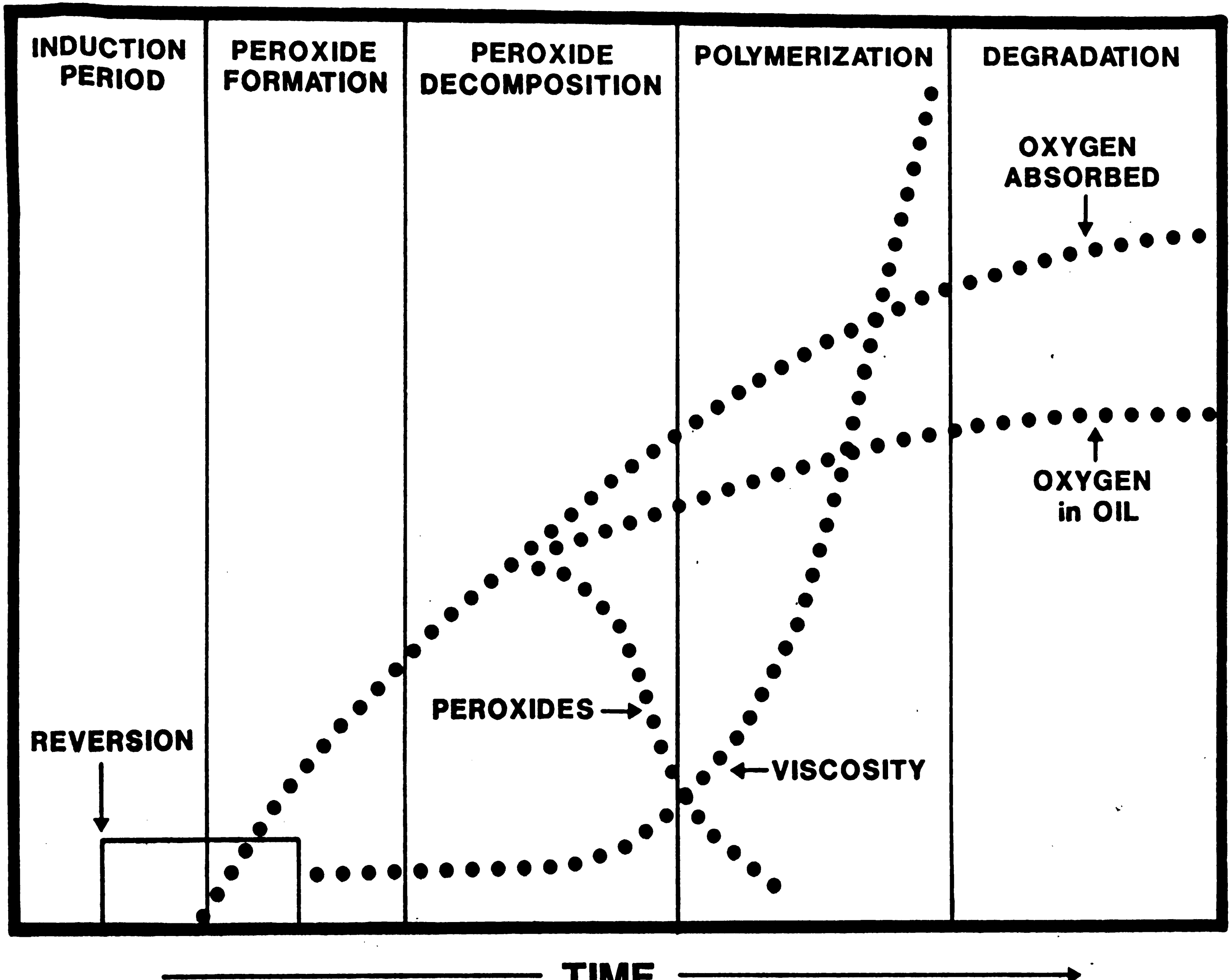


Figure 5. The stages of oxidation of a fat (Perkins, 1967).

considered suspect if it does not have a rancid flavor (Bennion, 1972). Oxidation occurs from the uptake of oxygen by unsaturated fatty acid components. Oxidation of food fats proceeds in a logarithmic scale due to the auto-catalytic nature of the reaction. Three phase of oxidation include initiation, propagation and termination (Bennion, 1972; Dugan, 1976). The initiation phase involves the formation of free radicals. In this stage, activation of an organic substance, usually at a double bond, causes the release of hydrogen and the resulting free radical:

Initiation

$$\text{RH (organic substance)} \xrightarrow{\text{activation}} \text{R}\cdot \text{ (free radical)} + \text{H}\cdot$$

Propagation occurs when oxygen is added to form a diradical:

Propagation

$$R\cdot + O_2 \rightarrow RO\cdot$$

$$RO_2\cdot + RH \rightarrow R\cdot + ROOH$$

When two radicals interact termination occurs:

Termination

$$R\cdot + R\cdot \rightarrow RR$$

$$ROO\cdot + ROO\cdot \rightarrow ROOR + O_2$$

$$RO\cdot + R\cdot \rightarrow ROR$$

$$ROO\cdot + R\cdot \rightarrow ROOR$$

$$2RO\cdot + 2ROO\cdot \rightarrow 2ROOR + O_2\cdot$$

The hydroperoxides and peroxides formed from this set of reactions are odorless and tasteless and therefore would not impart the characteristic rancid taste and odor. Aldehydes, ketones and esters formed from scission, dismutation and reactions of the peroxides and hydroperoxides are the compounds which produce the characteristic rancid flavor and odor (Dugan, 1976). Free radicals are also released during these reactions which can thus promote further oxidation. The oxidation product is dependent upon the original fatty acid from which it was formed, thus the types of oxidation products can lend a clue to the fatty acid from which it was formed. Pentanal and hexanal contents are commonly used to test for oxidation of oils by gas-liquid chromatographic techniques (Warner, 1978)

Polymerization. Polymerization of oils can occur with the resulting increase in viscosity. Thermal polymers form via Diels-Alder reactions between unsaturated fatty acyl groups after conjugation has taken place (Perkins, 1967) (Figure 6). These polymerization reactions may occur between two triglycerides by intermolecular dimerization or by reaction between unsaturated fatty acyl groups on the same triglyceride molecule, referred to as intramolecular dimerization (Ryan, 1982). Conditions leading to

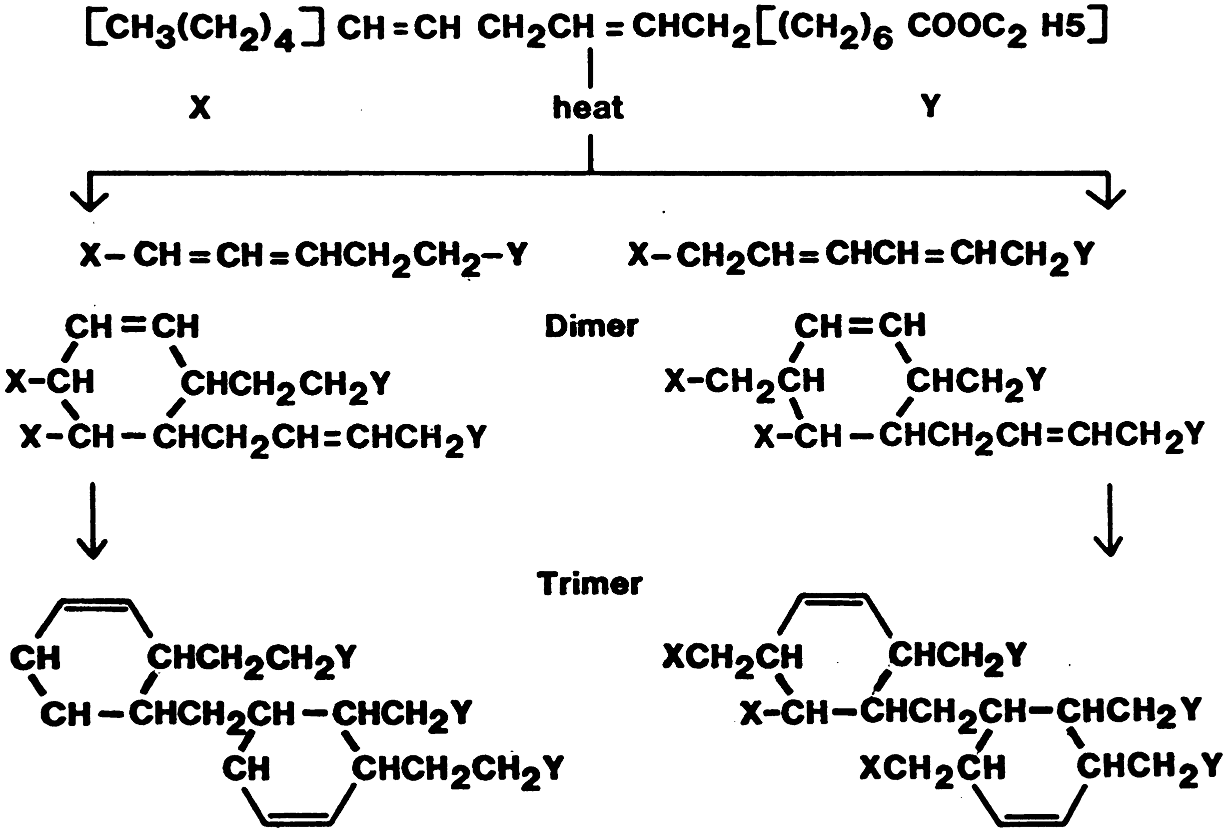


Figure 6. Polymerization of triglycerides (ethyl linoleate) (Perkins, 1967).

polymerization of the lipids are heat stress, oxidation, and the presence of radical or polar catalysts (Dugan, 1976). Polymerization products are thought to be responsible for the adverse health effects attributed to abused fats and oils (Perkins, 1960).

Hydrolysis. Hydrolysis (Figure 7) may occur in the fats releasing volatile short chain fatty acids, resulting in disagreeable flavors and odors. Although long chain acids are also produced by hydrolysis, these do not usually contribute to off flavors unless oxidation occurs (Bennion, 1972). Carlen *et al.* (1954), Baueverlen *et al.* (1968), and Roth and Rock (1972) found hydrolysis to be of secondary importance to oxidation.

Health Effects of Heated Oils. Much has been speculated about the oxidation and polymerization products of oil and human health. Perkins (1960) found that animals fed oxidized oils developed vitamin deficiencies. Alexander (1978) reported the effects of slight depression in growth all the way to very poor growth, diminished feed efficiency, increased liver size, fatty necrosis of the liver and various other organ lesions. However, the conditions used on the oil to promote these effects are far more severe than those used in the practical cooking or processing of foods (Rice *et al.*, 1960; Poling *et al.*, 1960; Keane, 1959 ; Perkins and VanAkkeren, 1965; Melnick *et al.*, 1957). For a complete review of the health effects

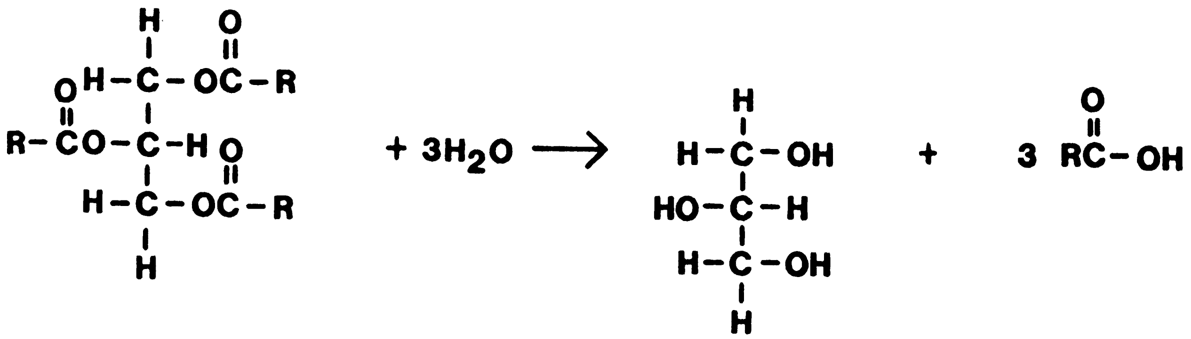


Figure 7. Hydrolysis of triglycerides.

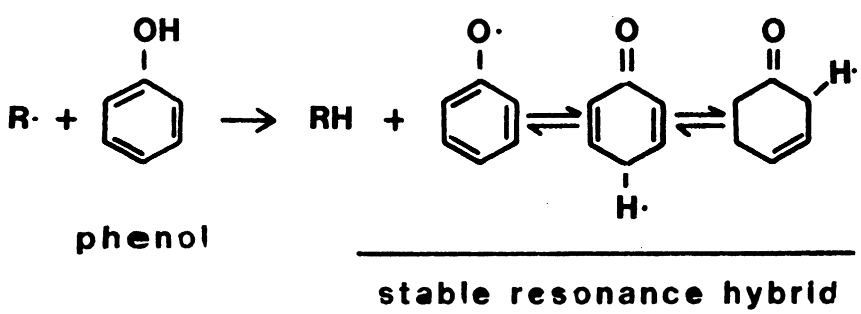


Figure 8. Phenolic "stable resonance hybrid" (Sherwin, 1972.

of heated oil see Ryan (1982).

Frying Technology

Type of Fat Used for Frying. The type of fat used for frying can affect the rate and degree of oxidation. Vegetable oils are found to be prone to oxidative changes during frying and become rancid rapidly at ordinary frying temperatures due to the high amount of unsaturated fatty acids. Hydrogenation of vegetable oils makes them more suitable for deep fat frying purposes. Animal fats, with lesser amounts of unsaturated fatty acids are highly resistant to oxidative changes, especially when hydrogenated. Tallow has a superior degree of resistance to oxidation, better than that of hydrogenated vegetable oils or lard (Baeuerlen *et al.*, 1968). Degradation as measured by darkening of color was not noticeably affected by source of fat, that is, animal or vegetable (Bates, 1952; Lowe *et al.*, 1958). Thompson *et al.* (1967) indicated that the degree of deterioration was independent of their degree of unsaturation but rather dependent upon how they were used.

Care of Fat and Equipment. Perkins and VanAkkeren (1965) and Ryan (1982) found that intermittently heated oils exhibited a greater degree of degenerative changes, as evidenced by increased viscosity, over continuously heated oils. This, in part, can be explained by the greater degree of oxygen available in the heating and cooling period when steam rising off the oil does not protect it. It is possible that intermittent heating, cooling and heating cycles would encourage the destruction of the oil through an increased buildup of peroxides and carbonyl compounds which may be destroyed by subsequent heating (Perkins and VanAkkeren, 1965). Although Baeuerlen and coworkers (1968) report that turning off the heat when not required will improve turnover of fat, which is an indication of a high quality product being developed. Perkins and VanAkkeren (1965) found that a high overall turnover rate of used oil may not increase the useful life of a fat when the daily turnover of fat is small. Fat turnover increases the length of time a fat can be used as well as filtering and refrigeration of the fats (Rust and Harrison, 1960).

Filtering of the oil and washing of the fryers improve the stability of the oils by reducing contaminants. Burnt food particles suspended in the frying medium tend to impart a bitter taste as well as an objectional speckled appearance to the fried product. The more burnt particles present, the more pronounced will be the bitter flavor (Baeuerlen et al., 1968). Gums formed on the surface and sides of the fryer which are removed during filtering and cleaning will also improve the life of a fat (Baeuerlen et al., 1968). Improper heating elements can also accelerate the degradation of fat as well as intense heat such

as that over a flame (Carlin _et al._, 1954). The uniform distribution of heat was emphasized by Strock _et al._ (1967) who found that a 10% increase in frying load could be attained with homogenous temperatures in the frying kettle.

Proper kettle design can help minimize deterioration of the frying fat. Robertson (1967) cited two principles which should be followed for kettle design. The first principle was that the amount of fat held in a system should be the minimum amount necessary to fry the product. The second principle stated that maximum production capacity should be maintained or that frying should be done for one long interval rather than several shorter ones.

The composition of the kettle, valves and lines can have an effect on the stability of the oil. Copper, along with brass, must be avoided due to the pro-oxidative effect of the copper. Robertson (1967) tested various types of metals and found aluminum, nickel and stainless steel to be the least damaging in that order. However, if detergent is needed to wash the kettle, aluminum becomes impractical and the cost of nickel is prohibitive.

Aeration of the fat should be avoided as with increased aeration there is increased exposure of oxygen to the fat (Carlin _et al._, 1954). Aeration can be reduced by preventing "pouring" of hot fats and circulation through heat exchangers and filters under atmospheric conditions

(Carlin et al., 1954). Placing a floating cover on the hot oil when not in use can also reduce oxidation.

In addition to the previously mentioned factors, the length of time the fat is exposed to heat and temperature, mixed fatty acid composition and position of the fatty acid in the triglyceride, amount of fat heated, unit of surface area, and processing conditions used to refine, decolorize and deodorize the fat can contribute to the stability of a frying fat (Kilgore and Luker, 1964).

Fat Absorption. The major factors influencing the amount of fat which will be absorbed during frying are: 1) cooking time, 2) the cooking temperature, 3) the total surface area of the food, 4) the composition and nature of the food, and 5) the variation in smoke point temperature of the fat used (Bennion, 1972). Time and temperature of cooking are related in that at a lower temperature more time is required to fully cook the product to the desired degree of browning. Lowe et al. (1940) found that doughnuts cooked for 3 minutes at 170, 185, and 200^{o}C exhibited no significant differences in fat absorption, although the color of the doughnuts was different. Lowe and co-workers (1940) also found that rerolling and increased handling of the dough increases the fat absorption of the doughnuts by increasing the surface area.

Substrate Effect

The nature of the product or substrate, can influence the degradation of the oil. This effect can be manifest in three ways: 1) by the release of antioxidants or pro-oxidants from the substrate into the oil, thus protecting the oil or catalyzing the free radical formation; 2) various functional groups could have a catalytic effect on secondary reactions or also on the free radical formation in the frying oil; and 3) the substrate by adsorption or chemi-adsorption may remove lipid oxidation products from the oil (Pokorny, 1980).

It has been long known that contaminant metals in the frying oil can catalyze free radical formation. Now, it is believed that hematin compounds present in meat (chicken) can leach from the product to increase the degradation of the oil (Kilgore and Luker, 1964). It was also found that the catalytic activity of hematin compounds in the chicken was offset by the deterrent effect of fat, amino acids or some unidentified protective agent in the meat (Kilgore and Luker, 1964). The protective effect of proteins was also studied by Pokorny (1980). It was found that the antioxidant effect of the protein in fried substrates (cod fish fillets) may be due to the effect of amino acid residues but phenolic and other compounds could contribute to this effect. Proteins are also found to bind oxidized fatty acids. These insoluble complexes are only partially digested, and with difficulty, which might contribute to the impaired digestibility of fried foods (Pokorny, 1980). Proteins, namely casein, have been found to bind copper, thus removing it from catalytic activity in the frying oil (Pokorny, 1980).

Much work has been done to simulate restaurant frying conditions using moistened cotton balls (Krishnamurthy et al., 1965; Chang et al., 1978; Reddy et al., 1968). It was found that the continuously heated oil was darker in color and had a higher viscosity than the oil which had been used to fry the cotton balls (Krishnamurthy et al., 1965). Chang and co-workers (1978) reported that the continuously heated oil (hydrogenated cottonseed oil) had a higher peroxide value.

Fats present in the product can migrate from the product and by dilution affect the oil. Kilgore and Luker (1964) found that no decrease in linoleic acid occurred in oils in which chicken was fried. It was thought that the degradation of linoleic acid probably occurred, but the slight dilution with chicken fat, which is approximately 20% linoleic, could have compensated for the loss.

Water as a component of the fried product can exert an effect on the stability of the oil. Jacobson (1967) reported that a 6% addition of water decreased the overall performance of the fat, and that a 24% addition improved the performance. Water present causes hydrolysis of the frying oil, especially if catalyzed by acidic components of the fried food (Pokorny, 1980).

Bennion and Hanning (1956) found a greater degree of decomposition in the oils which were used to fry doughnuts in comparison to potatoes. They went on to evaluate the specific batter ingredients and found milk, eggs and baking powder to be responsible for the resulting change. Bennion and Hanning (1956) explain the results by increased porosity of the doughnuts with eggs and baking powder. Pokorny (1980) believes the diffusion of phospholipids with the use of egg batters increases the free fatty acid content of the oil and thus decreases sensory appeal. Darkening of the oil when the egg was included in the batter was observed. This could be due to decomposition of the diffused phospholipids in the oil (Bennion, 1967).

Natural antioxidants are constituents of the substrate which provide a protective effect on the oil. Natural antioxidants are found in a variety of products: carrots, which are used in some frying production plants to delay the addition of fresh fat, offer a protective effect to the oil. It is the carotenoid pigments in the carrots which protects fat against oxidation under specific processing conditions (Pokorny, 1980). Potatoes contain natural inhibitors, the antioxidant effect located in the tuber juice (Pokorny, 1980). Defatted oat flakes have been found to provide a 28% protective effect to the oil in which they were fried (Pokorny, 1980). Herbs and spices may have a beneficial effect by diffusion of essential oils from these products (Pokorny, 1980). One of the most common naturally occurring antioxidants is tocopherol which is found in many vegetable oils (Dugan, 1976).

Antioxidants

Synthetic antioxidants are often added to increase the length of time the oil can be used and to increase the shelf life of the product. Antioxidants may be divided into two groups - primary antioxidants and synergists. Synergists act to enhance or prolong the action of the primary antioxidant and are usually acidic in nature (Bennion, 1972). The primary antioxidants act directly to interrupt the free radical chain mechanism in autoxidative processes. It is important that the free radical ($A^\cdot$) formed not have the ability of initiating or propagating the oxidation reaction. Phenolic compounds form a "stable resonance hybrid" which makes it unable to function as a competitor with the substrate for oxygen (Figure 8) (Sherwin, 1972) by the mechanism:

$$R^\cdot + AH \qquad RH + A^\cdot$$

$$R^\cdot + A^\cdot \qquad RA$$

$$RO^\cdot + AH \qquad ROH + A^\cdot$$

$$RO^\cdot + A^\cdot \qquad ROA \text{ etc.}$$

$$ROO^\cdot + AH \qquad ROOH + A^\cdot$$

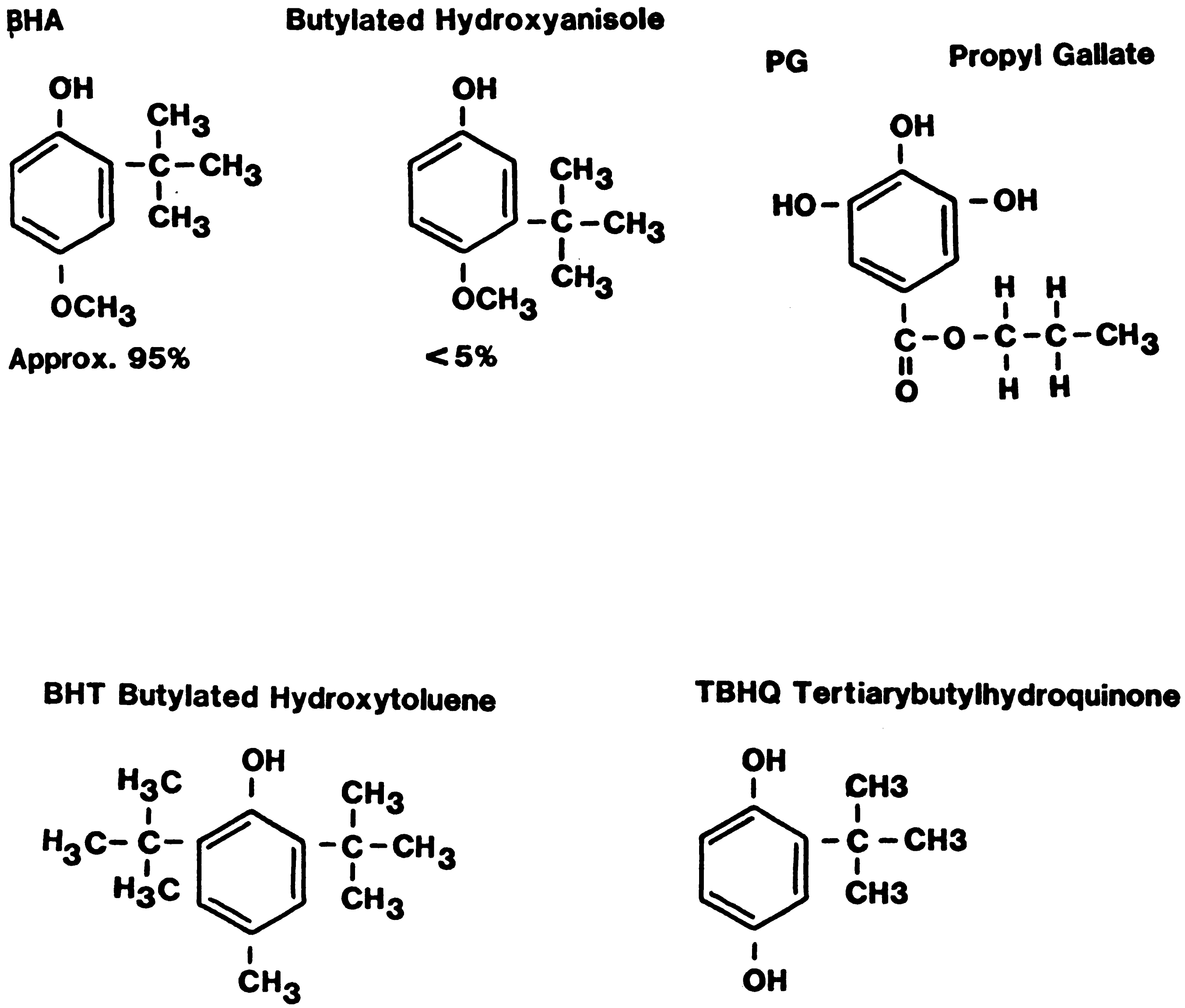


Figure 9. Some common synthetic antioxidants in use.

The use of antioxidants in deep fat frying is limited due to the removal of the antioxidant from the oil. Magoffin and Bentz (1949) list three processes by which this can occur: the first by steam distillation; the second by adsorption in the product; and the third by the normal process of consumption in performing its antioxidant role. Sair and Hall (1951) add to this list by including the destruction or oxidation of the antioxidant. These factors, along with the resulting poor carry through of the antioxidants into the food product makes the use of antioxidants in the oils used for frying of little value (Sherwin, 1972). Sair and Hall (1951) have found the use of antioxidant salt or an antioxidant dressing oil permits the complete utilization of the antioxidant, for use in potato chips and fried nuts.

Fats as Shortenings

In the cake system, fat acts to increase aeration of the batter which relates to a tender product with high volume, silky grain, and uniform cells of small size. Cake tenderness is affected by the presence of fat, which enables gluten strands to slide across one another. Fat also inhibits excessive gluten formation by physically interferring with gluten strand development (Bennion, 1972). Fats can be functionally characterized by their dispersion, shortening power and aeration ability.

Dispersion

Dispersion of a fat refers to the degree of incorporation of the fat into the batter system. Without adequate dispersion the batter is likely to have low aeration properties and decreased shortening power. Dispersions of a fat, or the surface area covered by fats, is dependent upon the cohesion, adhesion, interfacial tensions and molecular attractions between water and organic liquids (Bennion, 1972). Fat containing both polar and non-polar groups (hydrocarbon chains) is dispersed in relation to the chain length of fatty acid residues with the unsaturated acids covering much greater areas per molecule than the saturated ones (Bennion, 1972).

Shortening Power

Fats contribute their shortening ability to two interrelated factors; their molecular composition and their crystalline habits (Moncrieff, 1970). The molecular composition of a fat governs the ratio of solid triglyceride to liquid components. This directly affects the aeration ability of the batter. Liquid shortenings have antifoaming properties which alone, would be ineffective in the cake system (Campbell, 1972). The fatty acid profile of the fat also plays an important role in the shortening ability by affecting the compositional differences relating to liquid and solid components. These compositional differences affect the crystalline properties of the fat (Bennion, 1972).

Aeration

Batter aeration is a property associated with fat in the cake system. Although air bubbles and fat particles are dispersed separately throughout the batter, gas pockets form most readily at points of cleavage along fat boundaries (Carlin, 1944). The size of the crystal is an indication of the size of the air bubble formed. The β' stable crystals are delicate crystals no larger than one micron (μ) in length. The intermediate crystals range from 3-5 μ and β crystals are course and large, averaging 25-50 μ in length (Hoerr, 1960). The β' crystals have air bubble patterns one micron or less in diameter, the intermediate crystals present a coarses pattern of air cell distribution and the β crystals form large bubbles (Hoerr, 1960). To achieve maximum aeration and the resulting silky grain, the fat must be uniformly dispersed throughout the batter.

MATERIALS AND METHODS

Deep-Fat Frying of Doughnuts

Materials

Fifty pound drums of edible beef tallow were obtained from Bunge Edible Oil Corporation, Kankakee, Illinois and stored at 4°C prior to use. All reagents and chemicals used in this investigation were of analytical grade. All ingredients utilized in the preparation of doughnuts were obtained from commercial sources prior to the start of frying, with fresh milk and eggs obtained daily. Superfine All Vegetable Liquid Frying Shortening (PVO International Inc.) was utilized as the control oil and stored at room temperature upon recommendation of the manufacturer. Superfine All Vegetable Liquid Frying Shortening is made from fully refined, partially hydrogenated vegetable oil (soybean oil) with TBHQ and citric acid added to preserve stability and methyl silicone added to inhibit foaming.

Fractionation of Tallow

Prior to the actual fractionation procedure, tallow was chipped from the fifty pound lot to obtain the desired amount for fractionation (6.5-7.5 kg) and warmed at 40°C for 8-10 hours. When the tallow was a semi-solid homogenous mixture and free from lumps, 0.6% sodium dodecyl sulfate (SDS) was added with constant stirring (Figure 4). The SDS acts as a surface active agent to better disperse the tallow components. The SDS-tallow mixture was allowed to remain at 40^{o}C for 18 hours. When this crystallization time elapsed, the electrolyte was added with deionized water and left to disperse for one hour at 40^{o}C. Sodium sulfate (0.15%) was the electrolyte of choice with 600 ml water added per kg of tallow. Five hundred ml plastic centrifuge bottles were filled with the tallow mixture and batches of six were placed in an International Equipment Company model K, size 2 centrifuge for 15 min at 2700 rpm. Centrifugation resulted in separation of olein (liquid) and solid fractions. The olein fraction was further allowed to crystallize at 30^{o}C for 18 hr without further addition of SDS. Centrifugation followed with the resulting separation of olein and solid fractions. The olein fraction was again collected and allowed to crystallize at 20^{o}C for 18 hr with further fractionation resulting after centrifugation. An effort was made to prevent fluctuations in temperature of the tallow during handling and centrifugation time. The solid fractions were not utilized in this experiment so, therefore, they were discarded. The tallow oils were stored at 4^{o}C prior to use.

Preparation of Doughnuts

The doughnut formula of Lowe *et al.* (1940) was utilized with some modification (Table 1). The type and amount of fat was adjusted to provide a neutral flavored, all vegetable shortening with the same degree of shortening ability as butter. The flour content was adjusted to provide a dough that was rollable but not overly stiff. The protein content of all purpose flour has decreased since 1940 which would make this flour adjustment necessary in order to have the equivalent amount of protein in Lowe and co-workers formulation (1940). The spice content of the doughnuts was adjusted due to pretest panelists comments.

The dough was prepared by the method of Lowe *et al.* (1940) as described in Table 2. The same Kitchen Aid Mixer (model K-5A) was utilized during preparation of the dough to minimize variations in dough characteristics. Slow speed was recorded at 25 rpm and medium speed at 145 rpm. The dough was rolled by hand onto a floured board between 1/4 inch cleats. Doughnut holes, 3.0 cm in diameter, were cut with a doughnut cutter and approximately 60 g of doughnut holes (count 8) were fried per batch.

Deep Fat Frying

Four Sears (Model 34-6425) deep-fat fryers with aluminum interiors and a capacity of 1365 g oil were used for

Table 1. Doughnut formulation (Lowe _et al._, 1940).

Ingredients	Lowe (g)	Experimental (g)
Sugar, fine granulated	200	200
Fat	25 (butter)	20 (hydrogenated shortening)
Eggs, fresh	96	96
Flour, all purpose	560	600
Milk, whole fresh	244	244
Baking powder (tartrate)	21	21
Salt	4	4
Nutmeg	1/8 teaspoon	0.40
Cinnamon	1/8 teaspoon	0.80

Table 2. Stepwise preparation of dough for doughnuts (Lowe *et al.*, 1940).

Preparation steps	Time (sec)	Speed[a]
Cream sugar, salt and fat	60	Medium
Add beaten egg	180	Medium
Add 1/2 milk and 1/2 flour (sifted with other dry ingredients)	60	Slow
Add remaining milk and flour	20	Slow
Scrape down, continue mixing	15	Slow
Scrape down, continue mixing	10	Slow

[a]Medium 145 rpm, slow 25 rpm.

the fryings. Fryers were rotated so that the same oil variable was not heated in the same fryer (Table 3). One thousand three hundred and sixty five g of each oil variable were preheated not longer than 20 min to 188^{o}C. The doughnut holes were fried for a total of 180 seconds, 90 seconds on each side. A drop in temperature of 3^{o}C occurred when the doughnuts were placed in the oil which resulted in a cooking temperature of 185^{o}C. Difficulty was experienced in maintaining the doughnuts on the frying side at any given time due to their tendency to roll. Two batches of eight doughnut holes were fried each day for four consecutive days.

To simulate a commercial frying operation, fat was added back to the fryers (approximately 100 g), to account for fat absorption, sample removal and drip loss, before the next day's frying began. After use, the oils were strained through a fine mesh screen layered with a double thickness of cheese cloth to remove dough particles. The fryers were washed with a mild detergent, rinsed completely and dried thoroughly. The oils were then stored in the fryer at 4^{o}C with tight covering lids until the next day's frying began. After frying the doughnuts were allowed to cool to room temperature on wire racks then prepared for sensory evaluation or frozen for further analysis.

Table 3. Rotation of fryers in deepfat frying.

Replication	Fryer			
	1	2	3	4
1	20	30	OT	C
2	C	20	30	OT
3	OT	C	20	30
4	30	OT	C	20

20 = 20 C tallow oil.

30 = 30 C tallow oil

OT = original tallow

C = control, superfine All Vegetable Liquid Frying Shortening.

Analysis of Oil

Color. Color of the heated oils was evaluated using a Hunter Color Difference Meter (model D-25) with an inverted head and white background. A standard yellow tile was used as a reference (L=78.5, La=-3.2, Lb=23.4). Oils were analyzed for color at approximately 70^{o}C and before straining. The oil samples were evaluated on the three scales, turned 90^{o} and a second set of measurements were taken. Results are given as average of the two values.

Viscosity. A 40 g oil sample was removed before straining at the end of each frying day. This sample was first used for viscosity, then other determinations. Viscosity was determined using a Nametre Direct Readout Viscometer model 7.006 in conjunction with an Exacal 100 controlled temperature circulating water bath at 50^{o}C ± 0.01^{o}C. The oil sample (approximately 35 g) was placed in a glass beaker (3.5 x 7.7 cm) and tempered in a circulating water bath. Samples were allowed to equilibrate 15 min. prior to obtaining a reading. The viscosity is given as centipoise-g/cm^3.

Fatty Acid Analysis. Oil samples prior to the first frying and after the last frying were analyzed for their fatty acid profiles. The samples were prepared for gas liquid chromatographic analysis using the boron trifluoride-methanol procedure described by Morrison and Smith (1964). The fatty acid methyl esters were analyzed as described by DeFouw (1981) with a 5840A Hewlett Packard gas chromatograph equipped with a flame ionization detector. A glass column, 2 m x 4 mm inside diameter, packed with 15% diethylene glycol succinate (DEGS) on 80/100 Chromosorb (Supelco Inc., Bellefonte, PA) was used. The gas chromatograph was operated isothermally at 190°C with a nitrogen flow rate of 33 ml/min. The temperature of the injector was maintained at 210°C and that of the detector at 400°C. Fatty acid percentages were calculated for C_{16}, $C_{16:1}$, C_{18}, $C_{18:1}$, $C_{18:2}$, and $C_{18:3}$ fatty acids using a 18850A Hewlett Packard microprocessing integrater.

Melting Point. Melting points of the oils prior to use and after each consecutive day of frying were determined by positioning the heated oils in a micro-capillary tube, sealing the end, freezing at -26°C and slowly heating the suspended capillary tube and thermometer in a circulating ice water bath or acetone dry ice bath determined upon the melting point of the oil sample.

Analysis of Doughnuts

Color. Both of the batches of doughnut holes fried daily were analyzed for color using a Hunter color Difference Meter (model D-25) with an inverted head and white background. A standard white tile (L=91.04, La=1.0, L_b= 0.9) was utilized for reference. Two readings were taken on each sample with the mean of the four values reported.

Texture. The doughnut holes were evaluated for tenderness using an Allo-Kramer Shear Press equipped with a TR-3 recorder. Five doughnut holes were weighed to the nearest 0.01 g and placed in the standard shear compression cell. The 3000 lb. transducer was used with a range of 300. Readings were recorded and pounds force to shear 1.0 g was calculated using the formula:

$$\text{lb force/g} = \frac{\text{transducer x range x reading}}{\text{sample wt (g) x 100 x 100}}\ .$$

Moisture. The A.A.C.C. Method 44-40 Moisture-Modified Vacuum Oven Method (1961) was followed to obtain percent moisture in the doughnut holes. The thawed, hand ground samples (2-3 g) were weighed to the nearest 0.0001 g and placed in predried, preweighed aluminum moisture dishes. The samples were dried at 90^{o}C for 12-15 hours under a vacuum of 27 inches of mercury in a Hotpack Vacuum Oven model 633. The samples were allowed to cool 30 min in a desiccator before being reweighed. Percent moisture was determined from the formula:

$$\text{\% moisture} = \frac{\text{original wt - dried wt}}{\text{original wt}} \text{ x } 100$$

Fat Absorption. Fat absorption was determined for the thawed, hand ground doughnut holes by the A.A.C.C. Method 30-25 crude fat in wheat and soyflour, feeds and cooked feeds (1962). A 4-5 g sample was accurately weighed to the nearest 0.0001 g and placed in a 3.3x8.0 cm Soxhlet thimble plugged with glass wool and gently lowered into a 50/55 soxhlet condenser. A 250 ml aliquot of reagent grade hexane (undistilled) was added to a 500 ml rounded bottom flask with 4-5 glass boiling beads. The apparatus was assembled and left to reflux for 6 hours on medium heat. The total volume of the filtrate was recorded and a 50 ml aliquot (using a 50 ml volumetric pipette) was removed for analysis and placed in a predried, preweighed 125 ml Erlenmeyer flask. Approximately 40-45 ml of the hexane were allowed to evaporate on a steam bath before the sample was placed in a 70^{o}C Labline (model 3615) oven under a vacuum of 30 inches of mercury for 12-15 hours. The samples were allowed to cool 30 min in a desiccator before being reweighed. Percent fat in the sample was determined from the formula:

$$\% \text{ fat} = \frac{\text{wt of extracted lipid (g)}}{\text{sample wt (g)}} \times \frac{\text{total vol of extract (ml)}}{\text{50 ml}} \times 100.$$

Fat content was expressed as percentage of total solids. Conversions were made by the formula:

$$\% \text{ fat (solid basis)} = \frac{\% \text{ fat (wet basis)}}{(100 - \% \text{ moisture of sample})} \times 100.$$

Sensory Evaluation. An eight member untrained panel was used to evaluate the doughnut holes. Each panelist was presented with four doughnut holes, each corresponding to a specific variable. The panelists were asked to judge each sample independently for crust color, tenderness, fat absorption and flavor on a 10 point descriptive linear line scale with 10 being optimum and 1 as poor. All evaluations were done in individual booths equipped with simulated daylight. The same eight panelists were used for the duration of the study.

Deep Fat Frying of Chicken

Materials

Fifty pound drums of edible beef tallow were obtained from Bunge Edible Oil Corporation, Kankakee, Illinois and stored at 4°C prior to use. All reagents and chemicals used in this investigation were of analytical grade. A common lot of chicken wings was obtained frozen from a commercial supplier. The batter for the chicken wings was prepared using Drake's Crispy Fry Mix manufactured by Drake's Batter Mix Company. Ingredients of the batter mix consist of wheat flour, cornmeal, salt, whey, bob-fat, dried milk, sodium bicarbonate, ground herbs, and spices.

Fractionation of Tallow

Beef tallow was fractionated as discussed previously for deep fat frying of doughnuts.

Preparation of Chicken and Batter

The chicken wings needed for each day of frying were thawed prior to use. Batter for the chicken was prepared following the package directions, 1.1 g water: 1 g mix. Just prior to frying the wings were submerged in the batter to coat the pieces thoroughly.

Deep Fat Frying

Four Sears (Model 34-6425) deep fat fryers with aluminum interiors and a capacity of 1365 g oil were used for the fryings. Fryers were rotated so that the same oil variable was not heated in the same fryer (Table 3). After use, the oils were strained through a fine mesh screen layered with a double thickness of cheese cloth to remove batter particles. The fryers were washed with a mild detergent, rinsed completely and dried thoroughly. The oils were then stored in the fryers at $4^{o}C$ with tight covering lids until the following trial.

A 1000 g sample of each oil variable was preheated not longer than 20 minutes to $200^{o}C$. Three wings were fried in each batch for 10 minutes. An initial drop of $10^{o}C$ was experienced such that the cooking temperature remained approximately $190^{o}C$. Three batches of wings were fried daily for four consecutive days. To simulate a commercial fat was added back to the fryer to maintain 1000 g for each days frying. Approximately 150 g were added back daily to replace fat adsorption, drip loss and sample removal. After frying, the wings were allowed to cool to room temperature on wire racks, then prepared for sensory evaluation or frozen for further evaluation.

Analysis of Oil

Color. Color of the oils was evaluated as described previously for deep fat frying of doughnuts.

Viscosity. Viscosity of the oils was evaluated as described previously for deep fat frying of doughnuts.

Analysis of Chicken Wings

Color. Due to the size of the chicken wing and the non-uniformity of surface flatness, color results using the Hunter Color Difference Meter could not be accurately determined.

Moisture. The method described for calculating percent moisture of the doughnuts was followed for the chicken wings. The sample included only ground homogenous batter.

Fat Absorption. Fat absorption by the chicken was determined from the fried batter. Batter was removed entirely from one wing and ground for 45 seconds in a Waring Blender (model 1120). The procedure followed that described for deep fat frying of doughnuts.

Sensory Evaluation. An eight member untrained panel was used to evaluate the chicken wings. Each panelist was presented with four chicken wings, each corresponding to a specific oil variable. The panelists were asked to judge each sample independently for crust color, tenderness, fat absorption and flavor using a 10 point descriptive scale. The chicken samples were evaluated after they had been heated for 60 seconds in an Amana Radarange Microwave Oven (model RR 9TA) on full power.

White Layer Cakes

Materials

A four hundred pound drum of edible beef tallow was obtained from A.W. Stadler Company, Cleveland, Ohio and stored at $4^{o}C$ prior to use. All reagents and chemicals used in this investigation were of analytical grade. All ingredients were obtained from commercial sources in common lots and stored at room temperature until use. Vanall Cake Emulsifier was obtained from Patco Products. Vanall is a hydrated (66%) blend of Sorbitan monostearate, glycerol monostearate, polysorbate 60; with propylene glycol, lactic acid and sodium propionate included as preservatives.

Fractionation of Tallow

In this investigation, solid and olein fractions were utilized with the crystallization temperatures of 40^{o}, 35^{o}, and 25°C. The resulting 35°C olein and 25°C solid fractions were utilized as shortenings. The fractionation procedure followed that described for deep fat frying of doughnuts.

Formulation and Preparation of Cake

Formulation and preparation of the cakes followed the A.A.C.C. Method 10-90, Baking Quality of Cake Flour. The formula is given in Table 4, along with modifications. The formula was scaled down to be applicable to a seven inch diameter cake pan. Pretesting determined the optimum water level in the formula and optimum baking time. Emulsifier was added at the 3.0% level as suggested by the manufacturer and recommended by Bundy _et al_. (1981). The amount of baking powder was determined by the Barometric pressure on the day of bake (A.A.C.C. Method 10-90 page 3 of 3).

The A.A.C.C. Method 10-90 was followed for the preparation of white layer cakes. The same Kitchen Aid Mixer (model K-5A) was utilized during each preparation of the cake batters to minimize variation in batter characteristics. Low speed was recorded at 100 r.p.m. and medium speed at 200 r.p.m. The cakes were baked individually at 375°F in a Rotary Hearth Test Baking Oven (model MF-2-665KLP220) for 25 minutes. Four replications were performed on each variable.

Table 4. White layer cake formulation, AACC Method 10-90 with modification.

Ingredient	AACC Method 10-90		Modification	
	g	%	g	%
Cakeflour (14% moisture basis)	200.0	100.0	87.50	100.00
Sugar (Baker's special)	280.0	140.0	122.50	140.00
Shortening	100.0	50.0	43.75	50.00
Nonfat dried milk	24.0	12.0	10.50	12.00
Dried egg white	18.0	9.0	7.88	9.00
Salt	6.0	3.0	2.63	3.00
Baking powder	a	a	4.59	5.25
Water, distilled	b	b	130.55	145.00
Emulsifier	-	-	2.63	3.00

[a]Optimum determined by Barometric pressure on day of bake.

[b]Optimum inclusion determined by pretesting.

Analysis of Batter

Specific Gravity. Specific gravity of the cake batters was determined gravimetrically at 23^{o}C using the formula:

$$\text{specific gravity} = \frac{\text{wt of substance + cup - wt of cup}}{\text{wt of water + cup - wt of cup}} .$$

Viscosity. Batter viscosities were determined using a Brookfield viscometer, Model RVT, which utilizes a rotating spindle (no. 6) and variable speed (speed 10). Readings were recorded and viscosity (centipoise) was calculated from the formula:

centipoise (cp) = reading x factor; where the factor = 1000 for spindle 6 and speed 10.

Analysis of Cakes

Cakes were proportioned for analysis as shown in Figure 10.

Volume. Volume of the baked product was determined by rapeseed displacement utilizing the National Loaf Volumeter with a 1000 cc capacity. Frozen cakes were cut in half with the sum of the volume of both halves of the cake recorded as the total volume. Volume index, and additional volume measurement, was determined utilizing the Layer Cake Measuring Template (A.A.C.C. Method 10-91).

Layer Cake Measuring Template (A.A.C.C. Method 10-91). Volume index, symmetry index, uniformity index and shrinkage

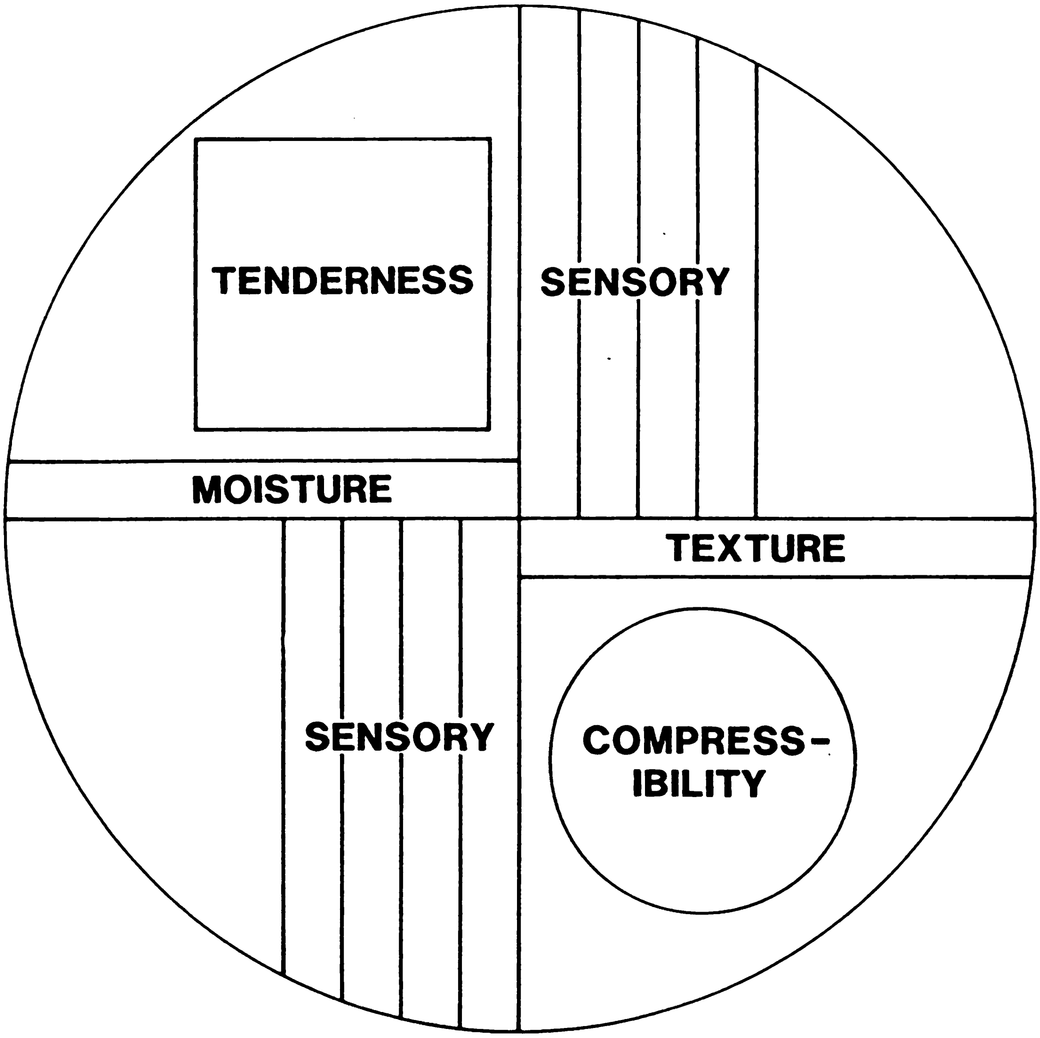


Figure 10. Preparation of baked cakes for analysis.

were measured on the half cakes. Figure 11 diagrams the layer cake measuring template.

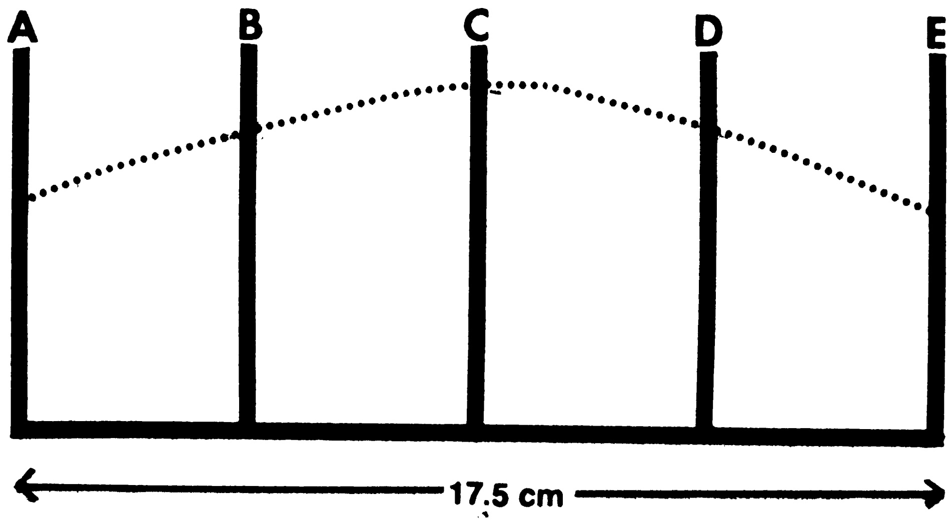


Figure 11. Diagram of the Layer Cake Measuring Template.

From the following formulae, the index values and shrinkage can be calculated:

volume index = B + C + D

symmetry index = 25 - B - D

uniformity index = B - D

shrinkage = 17.5 cm - (distance A through E)

Tenderness and Compressibility. Tenderness (pounds force per gram to shear) and compressibility (pounds force to compress) were recorded for each variable with the use of an Allo-Kramer Shear Press equipped with a TR-3 recorder. Round (compressibility) and square (tenderness) forms were used to cut standard samples and those for tenderness evaluations weighed to the nearest 0.01 g. A standard shear compression cell was used to measure tenderness. The 3000 lb. transducer was used with a range of 10. Readings were recorded and pounds force per gram to shear was calculated using the formula:

$$\text{lb force/g} = \frac{\text{transducer x range x reading}}{\text{sample wt (g) x 100 x 100}}.$$

Compressibility was determined using a round plunger (Model SC 116) which compresses the cake sample against a platform. The 100 lb. transducer was utilized with a range of 33. Readings were recorded and pounds force to compress was calculated from the formula:

$$\text{lb force} = \frac{\text{transducer x range x reading}}{\text{100 x 100}}.$$

Moisture. Moisture content of the baked products was determined by the procedure outlined for doughnuts.

Texture. Texture of the baked product was determined by scanning electron microscopy (SEM). Randomly selected cube samples were freeze dried for 24 hours, mounted on aluminum stubs, and gold coated with a sputter coater for 9 to 12 minutes. The prepared samples were examined in a Japan Electrol Optics Limited SEM, Model JSM 35C, at an accelerating voltage of 15 KV and 20 X magnification.

Sensory Evaluation. Cakes were judged by an eight member untrained taste panel for cell uniformity, size, and thickness of walls; grain; texture, moistness, and softness; crumb color; and flavor. The A.A.C.C. Method 10-90 score card was utilized. The conditions of the evaluation were similar to those described for doughnuts.

RESULTS AND DISCUSSION

This study was designed to investigate the functionality of detergent-fractionated beef tallow and original beef tallow in food systems. The application of these tallow fractions as well as intact tallow was studied in deep fat fried foods and baked products, with both objective and subjective analyses being conducted.

Deep Fat Frying of Doughnuts

In this phase of the investigation, original beef tallow and two beef tallow olein fractions (20 and 30°C) were evaluated as frying media for dough systems. In order to simulate a commercial operation, fresh fat was added back to the fryer after every other fry.

Doughnut Analyses

Tenderness of the doughnut holes as measured on an Allo-Kramer Shear Press revealed that the control sample (Superfine All Vegetable Liquid Frying Shortening) doughnut required more force to shear (194.6 lb/g) and was significantly ($p<0.05$) less tender than either the original tallow sample (169.3 lb/g) or the doughnut prepared using the 20° and 30°C fractions (181.3 lb/g and 178.5 lb/g, respectively, Table 5). A statistically significant difference was noted among fries for this evaluation. Increased use of the oils produced doughnuts which were significantly less tender.

The color, or degree of browning of the fried product is an indication of the quality of the oil. Irregular browning and decreased overall browning of the fried products is an indication of overuse of the frying oil (Artman, 1969). Color of the doughnut holes was consistent throughout the frying replications, thus degradation of the oils was not indicated. No statistically significant difference was found among doughnuts for all tallow samples and the control (Table 5). DeFouw _et al_. (1981) reported a significant difference between color of sliced fried potatoes over a period of twenty fryings utilizing 25^{o}, 35^{o}, 40^{o} and $45^{o}C$ tallow fractions. Fried potato slices were darkest and most red after the first frying: however the color of the fried sliced potatoes from the sixth through the twentieth frying did not differ significantly. Rust and Harrison (1960) also found that french fried potatoes did not brown after approximately 19 frying periods. DeFouw (1981) attributed the lack of browning to the decreased ratio of potato slice weight to oil weight. Adding fresh fat back to the fryer will increase this ratio and extend the useful life of an oil (Melnick, 1957b; Artman, 1969). Adding back of fat dilutes the

Table 5. Physical characteristics of doughnuts deep fat fried in commercial frying oil, original tallow, and two beef tallow fractions.

Characteristics[A]	commercial frying oil[B]	original tallow	fractions	
			$20^{o}C$	$30^{o}C$
tenderness, lb/g	$194.6^{a}\pm15.6$	$169.3^{b}\pm7.3$	$181.3^{b}\pm15.5$	$178.5^{b}\pm13.5$
fat absorption, %	$23.23^{a}\pm2.44$	$27.46^{a}\pm3.24$	$24.62^{a}\pm3.94$	$23.85^{a}\pm2.64$
moisture, %	$18.32^{a}\pm0.48$	$17.54^{a}\pm0.89$	$19.00^{a}\pm1.41$	$17.68^{a}\pm0.84$
Hunter Color				
L	$30.8^{a}\pm2.2$	$29.9^{a}\pm1.2$	$29.9^{a}\pm2.2$	$31.9^{a}\pm1.9$
a	$19.7^{a}\pm1.4$	$19.8^{a}\pm1.2$	$20.0^{a}\pm0.7$	$20.1^{a}\pm0.6$
b	$15.6^{a}\pm1.7$	$14.8^{a}\pm1.4$	$14.9^{a}\pm1.6$	$16.6^{a}\pm1.0$

[A] Based on four replications.

[B] Superfine All Vegetable Liquid Frying Shortening (PVO International Inc.).

[abc] Row means followed by same letter indicate no significant difference ($p<0.05$).

degradation products, as well as producing a fresh matrix for frying (Ryan, 1982).

Speckled appearance of foods fried in used oils has been reported (Beaverton *et al*., 1968). Speckling was not found for the doughnuts fried in any of the oil samples, most probably due to filtering of the oil and washing of the fryers after every second fry.

The doughnuts fried in original tallow had the highest degree of fat absorption, 27.46% although no significant differences were found between samples. The control sample had the lowest fat absorption (23.23%), while the 20^{o} and $30^{o}C$ fraction doughnuts contained 24.62 and 23.85% fat, respectively. Fat absorption in fried foods is related to time and temperature of cooking as well as total surface area and composition of the food (Bennion, 1972).

Time and temperature of cooking are related to fat absorption, such that at a lower temperature more time is required to fully cook the product. Thus, the product is in contact with the oil for a longer period of time. Lowe *et al*. (1940) reported that there were no significant differences in fat absorption for doughnuts cooked at three temperatures, 170^{o}, 185^{o} and $200^{o}C$, the cooking time being the same at all three temperatures. It is unlikely, therefore, that fat absorptin would be affected by the slight fryer temperature cycling experienced in this investigation.

Lowe *et al*. (1940) reported that fat absorption was influenced by dough temperature. If the dough was 24^{o}C, the doughnuts absorbed more fat and did not expand as much before cooking when the dough temperature was near 26^{o}C. The longer the dough was handled and rerolled the less fat was absorbed during frying (Lowe *et al*., 1940), quite possibly by the porosity effect experienced (Bennion and Hanning, 1956). The dough for doughnuts in this investigation was prepared in one batch for all frying on a given day. Therefore, the effect of dough temperature and handling would be negligible.

Used oils produce foods of poorer quality, the poorer quality being manifest as higher fat content, off flavors, irregular browning and poor appearance (Artman, 1969). In this investigation, fat absorption was not found to increase with increased frying which relates to an oil which was not overused. This is supported by consistent browning and acceptable appearance of the doughnuts and the lack of an increase in viscosity of the oil.

The moisture contents of the samples were found to range from 17.5 to 19.0%, although no significant differences were noted between samples (Table 5). It is possible that during freezer storage, a loss of moisture could have occurred which would account for the small differences in moisture contents.

Analyses of Oil

The viscosity of the original tallow sample was not significantly different from that of the tallow fractions, while the control sample was significantly less viscous (Table 6). In general, the viscosity of oils decreases slightly with an increase in unsaturation (Swern, 1964). The lower viscosity of the commercial frying oil, 29.5 cp-g/cc^3 could be due to the more unsaturated nature of this vegetable oil. The 20^{o}C olein tallow fraction is more unsaturated than the 30^{o}C olein fraction which is more unsaturated than the control (Table 7). Although no significant differences in viscosity were found, the unsaturation of vegetable oils increases the potential for oxidation and polymerization of the oil, with the concomitant increase in viscosity (Baeuerlen et al., 1968). Increased viscosity of the oils also relates to a frying medium with poor heat transfer properties (Artman, 1969).

It is significant to note that no increase in viscosity was found with increased fryings. This indicates that polymerization products were not formed to any significant level. This supports the work of Ryan (1982) who reported that both continuously and intermittently heated oils did not show an increase in viscosity until after 25 hours. DeFouw et al. (1981) in contrast, reported a significant increase in viscosity in the frying media after frying six batches of sliced potatoes. The difference

Table 6. Physical characteristics of commercial frying oil, original tallow, and two beef tallow fractions utilized to fry doughnuts.

Characteristics[A]	commercial frying oil[B]	original tallow	fractions 20°C	fractions 30°C
viscosity, cp-g/cc^3	$22.8^{a}\pm2.4$	$29.5^{b}\pm0.9$	$29.3^{b}\pm1.5$	$29.0^{b}\pm0.8$
Hunter color				
L	$18.0^{a}\pm0.4$	$21.1^{c}\pm2.5$	$19.6^{b}\pm0.2$	$19.6^{b}\pm0.3$
a	$-1.3^{a}\pm0.3$	$-3.4^{c}\pm1.6$	$-2.6^{bc}\pm0.2$	$-2.5^{b}\pm0.2$
b	$+2.7^{c}\pm0.3$	$-1.7^{a}\pm1.6$	$-0.7^{b}\pm0.6$	$-0.5^{b}\pm0.5$

[A] based on four replications

[B] Superfine All Vegetable Liquid Frying Shortening (PVO International Inc.)

[abc] row means followed by same letter indicate no significant difference ($p<0.05$)

in the present investigation could be attributed to the decreased number of batches fried, thus decreased number and length of time the fat was heated and to the fresh fat added back to the fryers.

Color of the oils was determined with the use of a Hunter Color Difference Meter which measured lightness of the oil (100L = white, 0L = black), redness or greenness (positive a = red, negative a = green, 0a = gray) and yellowness or blueness (positive b = yellow, negative b = blue and 0b = gray) (Table 6). In general, the commercial frying oil and the original tallow appeared to have significantly different color characteristics with the tallow oil fractions being not significantly different and located midway between the two extremes. The control oil was found to be darker, more red and more yellow than the original tallow oil. This is probably due to carotenoid pigments present in the soybean oil (DeFouw, 1981).

All oils appeared to darken with increased frying, although this difference was not significant. Artman (1969) reported the browning phenomenon accompanies the degradation of a heated fat. Lowe _et al_. (1940) reported that both degradation of the fat and accumulation of small food particles can account for the increased darkening of the oils with increased frying. Bates (1952) and Lowe _et al_. (1958) reported that darkening of color of the heated oils, as a measure of degradation, is not noticably affected by source of fat, whether it be animal or vegetable. Mokai *et al*. (1965), as cited by Artman (1969), attributed the darkening phenomenon of heated oils to the presence of α, β and α,α unsaturated carbonyl compounds formed via scission of hyperoxides. Polymerization products can also contribute to darkening of the oil (Perkins and Kummerow, 1959).

Specific batter ingredients contributed specifically to increased darkening of the oil. Bennion and Hanning (1956) reported a darkening of the oil when egg was included in fritter batter. This could be due to decomposition of the phospholipids which had diffused from the egg yolk into the oil (Bennion, 1967).

While no significant difference in the degree of darkening of the oil was observed, a significant difference existed in yellowness and blueness of the oil variables (Hunter color b). The original tallow sample and both beef tallow fraction oils were found to be significantly more yellow after fry four, although no difference in yellowness or blueness was found with additional fryings.

Fatty acid profiles for the original tallow, tallow fractions and commercial soybean oil are presented in Table 7. Kilgore and Luker (1964) reported a decreased level of polyunsaturated fatty acids with increased frying use of the oil. In this investigation, there were slight increases in the saturated fatty acid contents at the expense of

Table 7. Fatty acid composition of original tallow, two beef tallow fractions and commercial frying oil, initially and after eight fryings of doughnuts.

Fatty acid		Control		OT		30		20	
		Before	After	Before	After	Before	After	Before	After
Palmitic	C16:0	11.0	(11.2)	27.4	(28.5)	25.7	(27.4)	25.5	(27.1)
Palmitoleic	C16:1	0.1	(tr)	4.4	(4.4)	5.1	(5.4)	5.4	(5.3)
Stearic	C18:0	4.5	(4.4)	10.9	(19.8)	15.3	(14.8)	14.3	(14.1)
Oleic	C18:1	24.2	(24.2)	46.8	(45.2)	50.3	(49.0)	51.1	(50.8)
Linoleic	C18:2	52.6	(52.9)	2.4	(2.1)	2.6	(2.5)	2.6	(2.3)
Linolenic	C18:3	7.5	(7.3)	tr	(tr)	0.9	(0.8)	1.0	(0.3)

the unsaturated fatty acids after 8 fryings in all variables. DeFouw (1981) also reported this finding. Perkins (1967) reported that many popular frying fats are based on beef tallow because of the lower percentages of linoleic acid present, thus reducing the potential for oxidation.

Sensory Evaluation

Sensory evaluations of the doughnuts showed no significant differences for tenderness and crust color among all samples (Table 8). Tenderness was scored a minimum of 7.0 on a 10.0 point scale for all samples. Crust color was also scored favorably with all samples receiving a minimum of 8.0. While no significant differences were found between color of the doughnut holes, all doughnut variables did not have a uniform browning pattern. This is evidenced by the less than optimum scores and panelist comments. Doughnut holes were fried on one side, turned and fried on the second side. Difficulty was experienced in maintaining the doughnut holes on the second frying side. This can be explained by the formation of an air cell in the doughnut hole. The air cell contains carbon dioxide produced by the reaction of baking powder and water under the influence of heat.

Fat absorption was found to be significantly less acceptable in the control doughnut with a score of 6.8. The original tallow doughnut was rated as the highest with

Table 8. Sensory scores of doughnuts deep fat fried in commercial frying oil, original tallow, and two beef tallow fractions.

Characteristics[A]	commercial frying oil[B]	original tallow	fractions 20°C	fractions 30°C
tenderness	$7.0^{a} \pm 0.5$	$7.4^{a} \pm 0.4$	$7.1^{a} \pm 0.2$	$7.4^{a} \pm 0.4$
fat absorption	$6.8^{a} \pm 0.2$	$7.9^{c} \pm 0.7$	$7.3^{b} \pm 0.3$	$7.6^{bc} \pm 0.2$
crust color	$8.0^{a} \pm 0.7$	$8.4^{a} \pm 0.4$	$8.3^{a} \pm 0.2$	$7.9^{a} \pm 0.5$
flavor	$5.3^{a} \pm 0.9$	$7.7^{b} \pm 0.4$	$7.9^{b} \pm 0.3$	$7.6^{b} \pm 0.5$

[A] based on four replications; eight member taste panel; 10 pt sclae with 10 optimum, 0 poor

[B] Superfine All Vegetable Liquid Frying Shortening (PVO International Inc.)

[abc] row means followed by same letter indicate no significant difference ($p<0.05$)

a score of 7.9. The tallow fractions were located midway with scores of 7.3 and 7.6 for the 20^{o}C olein fraction and 30^{o}C olein fraction samples, respectively. These values do not correspond to the objective fat absorption results in which no significant difference in fat absorption was found. DeFouw et al. (1981) also reported this lack of continuity in fat absorption of fried potato slices. Original tallow fried potato slices were found to be less greasy by sensory evaluation than those fried in tallow fractions, although no significant difference existed among the objective fat absorption results for slices fried in original tallow and those fried in tallow fractions (with the exception of the 25^{o}C olein fraction).

The original tallow has a lower melting point, being a solid at room temperature (Table 1). This could impart a different mouth feel to the doughnuts and potato slices fried in original tallow. One of the principal uses of fats in food preparation is to impart textural qualities to the food including mouth feel (Bennion, 1972). The panel members might have related this difference in mouthfeel to a decreased greasiness and scored the sample thus.

Flavor was found to be equally acceptable among the doughnut holes fried in any of the tallow samples, although a significant decrease in acceptability was noted for the commercial frying oil (Table 8). The tallow samples (both fractions and original tallow) averaged 7.7, with the

Table 9. Melting point ranges[A] of original tallow, 20°C and 30°C olein tallow fractions and a commercial frying oil.

Oil	Melting point, °C
original tallow	41-43°
20°C fraction	21-23°
30°C fraction	23-26°
commercial frying oil[B]	-9.0-4.0°

[A]based on three replications

[B]Superfine All Vegetable Liquid Frying Shortening (PVO International, Inc.).

control doughnut achieving a score of only 5.3 on a 10.0 point scale. Figure 12 illustrates the flavor scores plotted against fry number. Flavor deterioration was not a problem with the doughnuts in this investigation. The low flavor scores for the control doughnut could be due to reversion of the commercial soybean oil. Soybean oil is classified as a linolenic acid vegetable oil. This class of oils, and soybean oil in particular, is susceptible to reverting in flavor to the undeodorized form of the soybean. The flavor and odor of the undeodorized or reverted soybean oil are described as "grassy", "beany" and "fishy" (Swern, 1964). These characteristic flavors and odors were reported by panelists for the doughnuts fried in the commercial soybean oil. The oil for the deep fat frying of doughnuts was purchased just prior to the start of this investigation.

Deep Fat Frying of Chicken

In this phase of the study, original beef tallow and two beef tallow olein fractions (20^{o} and $30^{o}C$) were investigated in the frying of a batter system. In order to simulate a commercial frying operation, fresh fat was added back to the fryers after every third fry.

Chicken Analyses

Fat absorption (dry basis) of the chicken wings ranged from 34.60% for the chicken fried in the $30^{o}C$ fraction to

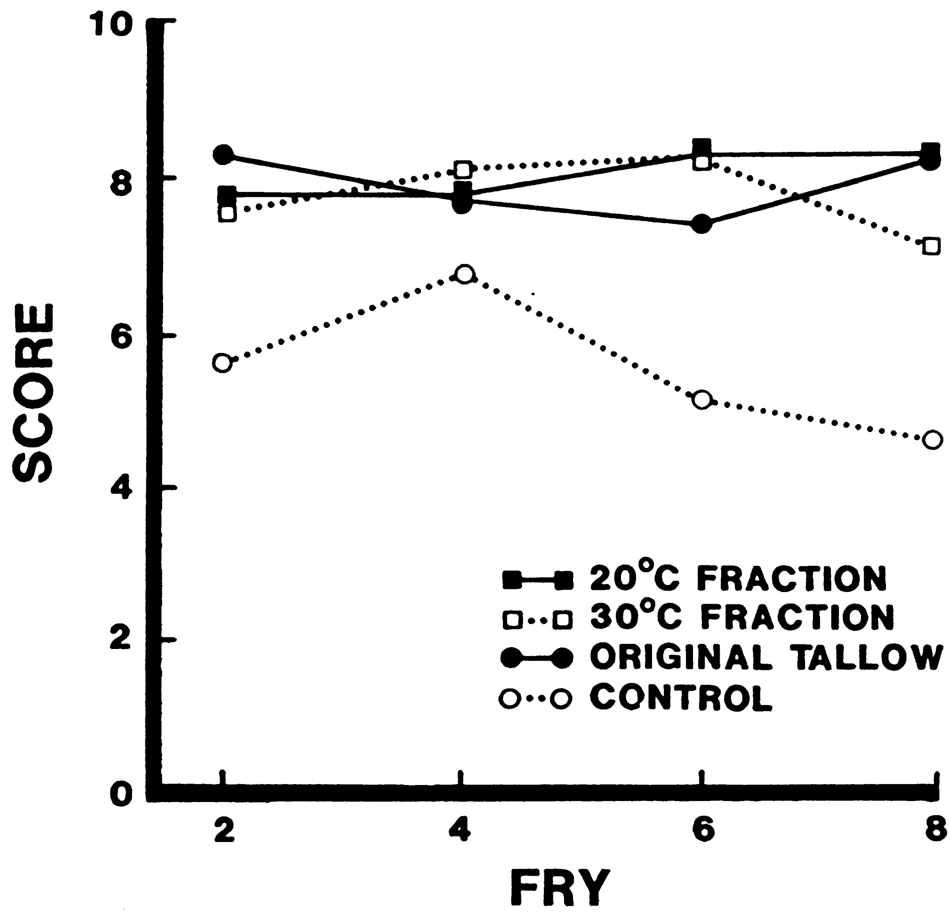


Figure 12. Flavor scores of doughnuts deep fat fried in original tallow, 20° and 30°C beef tallow fractions and a commercial soybean oil (control) plotted against fry.

40.24% for the control sample. The sample fried in original tallow and the 20^{o}C fraction sample contained 36.93% and 38.71% fat, respectively (Table 10). These differences are not significant. A large standard deviation was found for the 30^{o}C fraction sample. This also corresponds to a large standard deviation for moisture. No significant difference was noted for moisture. The average moisture content for all samples was approximately 26%. Both fat absorption and moisture contents were obtained from the breading only of the chicken wing. It is possible that the oil was absorbed into the chicken itself which would account for the large standard deviation noted. Pokorny (1981) reported the protective effect exerted by protein rich foods due to the adsorption or chemiadsorption of lipid oxidation products in the fried substrate. Kilgore and Lecker (1964) investigated the linoleic acid content of fried chicken and found less of a decrease in the oil used to fry chicken than in the oil used to fry potatoes. Neither of these investigations used battered food products.

A lack of uniformity in thickness of batter was experienced. Variable thickness of batter could result in varying levels of fat absorption and moisture loss. The batter mix contains baking soda and milk, both of which have been shown to increase fat absorption in doughnuts by increasing the porosity of the dough (Bennion and Hanning, 1956). The shape and variability of shape of the chicken

Table 10. Physical characteristics of chicken wings deep fat fried in commercial frying oil, original tallow and two beef tallow fractions.

Characteristics[A]	commercial frying oil[B]	original tallow	fractions	
			$20^{o}C$	$30^{o}C$
chicken fat absorption, %	$40.24^{a}\pm2.10$	$36.93^{a}\pm1.54$	$38.71^{a}\pm2.06$	$34.60^{a}\pm5.11$
moisture, %	$22.81^{a}\pm4.29$	$27.62^{a}\pm4.69$	$24.43^{a}\pm3.06$	$29.34^{a}\pm5.74$
oil viscosity, cp-g/cc^3	$25.4^{a}\pm1.3$	$28.8^{b}\pm0.5$	$35.6^{c}\pm1.9$	$35.4^{c}\pm2.2$
Hunter color				
L	$16.7^{a}\pm1.2$	$19.2^{b}\pm0.4$	$19.3^{b}\pm0.3$	$19.0^{b}\pm0.6$
a	$3.2^{b}\pm2.0$	$1.0^{b}\pm0.5$	$0.8^{b}\pm0.4$	$0.8^{b}\pm0.6$
b	$10.8^{a}\pm0.2$	$8.5^{b}\pm1.0$	$8.6^{b}\pm0.9$	$9.4^{b}\pm0.3$

[A] based on four replications

[B] Superfine All Vegetable Liquid Frying Shortening (PVO International Inc.)

[abc] row means followed by same letter indicate no significant difference ($p<0.05$)

wings caused the batter to accumulate in some wing locations. To avoid this problem, deboned chicken of uniform size and shape should be used. Improper packaging of the chicken during freezer storage, repeated freezing and thawing could also account for the variable moisture and fat contents in addition to the factors discussed for doughnuts.

Analyses of Oil

The beef tallow fractions were found to have the highest viscosity followed by the original tallow and the control (Table 10). No significant difference ($p<0.05$) in viscosity was found between the fractions. However, the fractions were significantly more viscous than the original tallow, which in turn was significantly more viscous than the control. The control oil had the lowest viscosity of 24.4 cp-g/CC^3, which was very similar to the 22.8 cp-g/CC^3 found in the doughnut evaluation. The viscosity of the original tallow was also quite similar in both investigations with 28.8 cp-g/cc^3 in the chicken evaluation and 29.5 cp-g/cc^3 in the doughnut evaluation. The significant increase found in the 20^o and 30^oC fractions, 35.6 and 35.4 cp-g/cc^3 respectively, could be due to the increased use of the oils in the chicken evaluation than in the frying of doughnuts. A greater frying time was needed for chicken and three fries per day were utilized in contrast to two fries per day for doughnuts.

The increase in viscosity of the fractions could be explained by the increased unsaturation of these oils in comparison to the original tallow. With increased unsaturation of an oil, a greater potential for oxidation and polymerization exists, which results in increased viscosity (Baeuerlen et al., 1968). The control oil which was more unsaturated than the tallow fractions only displayed a slight increase in viscosity in this investigation. No significant increase in viscosity was found with increased frying.

Color of the commercial oil was found to be significantly darker, more red and more yellow than any of the tallow oils which were all very similar. This color pattern was similar to that found for the oil used to fry doughnuts, with the exception of the differences noted between the original tallow and the fractions for the doughnut frying. Bates (1952) and Love et al. (1958) reported that darkening of color of heated oils is not noticably affected by source of fat, whether it be animal or vegetable.

Sensory Evaluation

Sensory scores for the chicken wings displayed a similar pattern to that of the doughnuts with no significant differences noted for tenderness and crust color

(Table 11). All samples for both tenderness and crust color scored at least 8.0. Fat absorption was rated as lowest in the 30°C fraction sample with a score of 5.5. All other samples scored 6.4 for fat absorption. This is inconsistent with the findings of the doughnut evaluation results. Overall, the scores were much lower for the chicken sensory fat absorption results, averaging 6.2 in contrast to those for the doughnut fat absorption averaging 7.4. The difference could be attributed to the thickness of the batter. This type of batter coating appeared to be relatively thick thus permitting a high degree of fat absorption. Panelist comments reflected a preference for chicken with a lesser amount of batter and therefore less greasy. The chicken was also heated before being sampled by the panelists which would impart a different mouthfeel upon the products.

Flavor for the chicken, like that of the doughnuts, was found to be significantly less acceptable for the commercial soybean oil which received a score of 6.8. The tallow samples ranged from 8.3 to 8.4. The chicken flavor scores were higher (averaging 8.0) than the doughnut flavor scores (averaging 7.1). The chicken was also fried longer which would lead to increased fat absorption over that of the doughnuts. Several reasons can be given to explain the overall higher flavor scores for chicken: 1) the panelists chosen were basically untrained, therefore error

Table 11. Sensory scores of chicken wings deep fat fried in commercial frying oil, original tallow, and two beef tallow fractions.

Characteristics[A]	commercial frying oil[B]	original tallow	fractions	
			$20^{o}C$	$30^{o}C$
tenderness	$8.0^{a} \pm 0.7$	$8.5^{a} \pm 0.6$	$8.6^{a} \pm 0.4$	$8.1^{a} \pm 0.6$
fat absorption	$6.4^{a} \pm 0.3$	$6.4^{a} \pm 0.6$	$6.4^{a} \pm 0.4$	$5.5^{b} \pm 0.5$
crust color	$8.4^{a} \pm 1.0$	$8.6^{a} \pm 0.7$	$8.6^{a} \pm 0.6$	$8.4^{a} \pm 0.6$
flavor	$6.8^{a} \pm 0.2$	$8.4^{b} \pm 0.4$	$8.3^{b} \pm 0.5$	$8.4^{b} \pm 0.3$

[A] based on four replications; eight member taste panel

[B] Superfine All Vegetable Liquid Frying Shortening (PVO International, Inc.)

[abc] row means followed by same letter indicate no significant difference ($p<0.05$)

could have occurred; 2) in the delicate flavor of the doughnut, the less acceptable oil flavors could have been more pronounced than in the chicken; 3) it has been reported that protein substances present in meat exerts a protective effect·in the oil (Pokorny, 1980); and 4) even though the oil in the fryers used for chicken was heated longer, a faster turnover rate was utilized, thus less chance for abuse could occur and the abused oil would be more diluted. Any or all of these reasons, alone or in combination, might possibly explain the finding. Figure 13 displays the flavor scores plotted against fry number. Flavor deterioration was not evidenced with chicken in this investigation.

White Layer Cakes

In the cake system, fat acts to increase aeration of the batter which results in a tender product with high volume, silky grain, and uniform cells of small size. The goal of this research was to compare the functionality of the 35°C olein fraction and the 25°C solid fraction with the fat from which the fractions were obtained (original beef tallow) and to evaluate the usefulness of the fractionation procedure. A standard high ratio white layer cake was also prepared using hydrogenated vegetable shortening for a control.

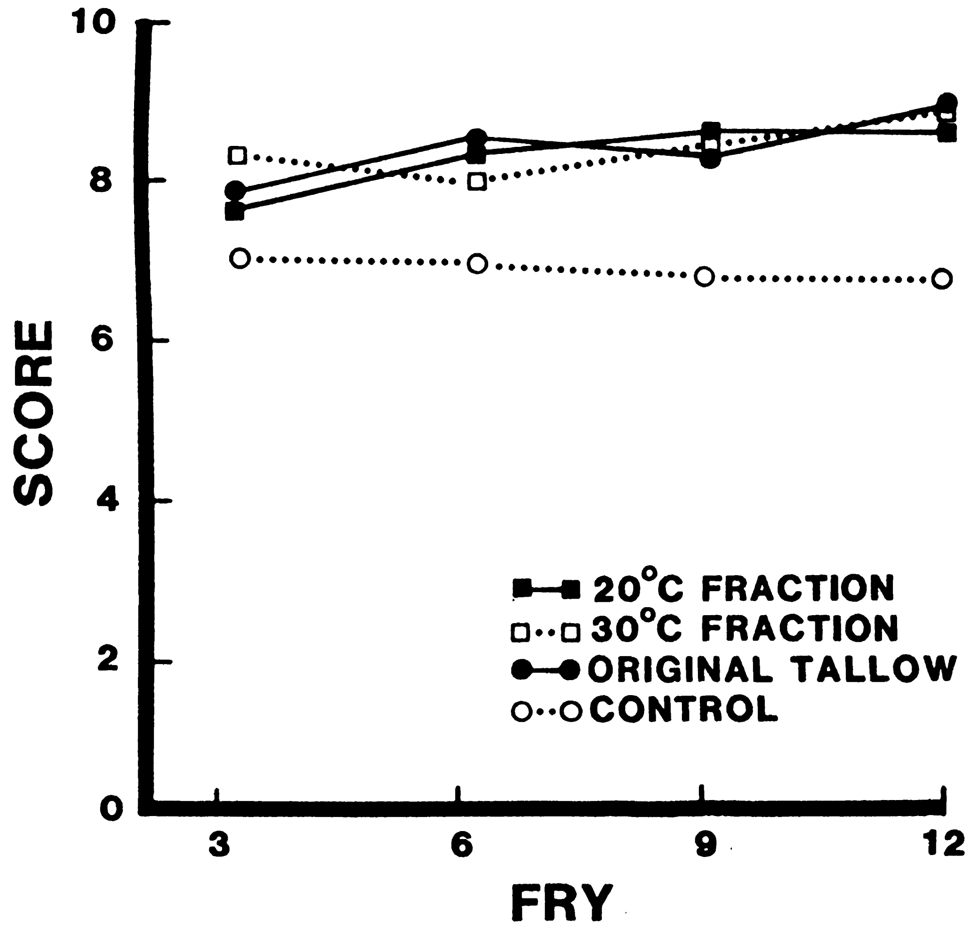


Figure 13. Flavor scores of chicken deep fat fried in original tallow, 20^{0} and $30^{0}C$ beef tallow fractions and a commercial soybean oil (control) plotted against fry.

Batter Analysis

Physical measurements on the cake batter revealed statistical significance ($p<0.05$) between the control and other variables for both viscosity and specific gravity (Table 12). Specific gravity of the batters ranged from 0.83 to 0.97 with the control cake batter having the lowest specific gravity of all of the cake batters. Viscosity readings correlate negatively with specific gravity. Low specific gravity and increased viscosity is an indication of increased aeration in the batter. Increased aeration in the batter will provide a cake of increased volume. The cake batter containing the $25^{o}C$ solid tallow fraction had the lowest air incorporation as evidenced by both a specific gravity of 0.97 and a viscosity of 16.7 poise.

The $25^{o}C$ solid fraction fat has more saturated fatty acids present and thus has a greater proportion of solid components (Bussey et al., 1981). This probably accounts for the decreased aeration ability found in the cake batter. The added emulsifiers aid in dispersion by interfacial action (MacDonald, 1968) but the amount of emulsifier added was probably not enough to overcome the dispersibility difficulties of this more solid fat.

Cake Analysis

Analysis of the physical measurements on the baked product revealed no statistical difference ($p<0.05$) in

Table 12. Physical characteristics of AACC White Layer Cakes prepared with commercial shortening, original tallow, and two beef tallow fractions.

Characteristics[A]	Commercial shortening[B]	Original tallow	Fractions	
			25°C solid	35°C olein
Batter				
specific gravity	$0.83^{a} \pm 0.02$	$0.90^{b} \pm 0.02$	$0.97^{c} \pm 0.05$	$0.90^{b} \pm 0.06$
viscosity (poise)	$36.4^{a} \pm 3.1$	$20.1^{bc} \pm 1.7$	$16.7^{c} \pm 5.4$	$26.2^{b} \pm 9.8$
Cake				
volume (cm^3)	$805^{a} \pm 17$	$778^{a} \pm 27$	$774^{a} \pm 27$	$760^{a} \pm 21$
tenderness (lb/g)	$1.23^{ab} \pm 0.05$	$1.40^{a} \pm 0.27$	$1.08^{bc} \pm 0.17$	$0.90^{c} \pm 0.12$
compressibility	$8.30^{a} \pm 2.80$	$10.88^{a} \pm 0.32$	$8.45^{a} \pm 2.39$	$8.90^{a} \pm 1.77$
volume index (cm)	$10.1^{a} \pm 1.6$	$9.6^{a} \pm 3.9$	$9.8^{a} \pm 2.9$	$9.8^{a} \pm 2.5$
symmetry index (cm)	$1.8^{a} \pm 1.0$	$1.0^{a} \pm 2.9$	$1.8^{a} \pm 2.2$	$4.5^{a} \pm 0.6$
uniformity index (cm)	$0.3^{a} \pm 3.0$	$0.8^{a} \pm 1.1$	$1.3^{a} \pm 1.2$	$0.5^{a} \pm 1.2$
shrinkage (cm)	$0.94^{a} \pm 0.06$	$0.83^{a} \pm 0.10$	$0.90^{a} \pm 0.22$	$0.93^{a} \pm 0.15$
moisture	$70.32^{a} \pm 1.18$	$70.39^{a} \pm 0.08$	$71.12^{a} \pm 0.17$	$71.17^{a} \pm 1.65$

[A]based on four replications

[B]Crisco, hydrogenated shortening (soy and palm oils); Proctor and Gamble

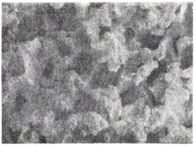
[abc]row means followed by same letter indicate no significant difference ($p<0.05$)

volume and volume index among any of the samples (Table 12). Volume of the baked products averaged approximately 775 cc. Even though statistical differences in specific gravity and viscosity of the batter existed, these differences in aeration did not effect volume of the baked products. No difference was noted for uniformity index, symmetry index and shrinkage. The term "uniformity" has been applied to measure cake symmetry and "symmetry" to indicate contour. Therefore, all cakes in this investigation had neither sunken centers nor peaked tops. Shrinkage for all cakes was less than one centimeter.

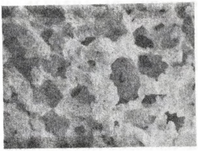
Tenderness of the cakes is an indication of the shortening ability of the fat. The tenderness values followed a trend with the cake shortened with the 35^{o}C olein fraction as the most tender with 0.90 lb/g force to shear, followed by the cake with 25^{o}C solid fraction sample with 1.08 lb/g, the control cake with 1.23 lb/g, and the cake prepared with the original tallow as the least tender needing 1.40 lb/g force to shear. No significant difference was found between the control cake and the cake prepared with the 25^{o}C solid fraction fat. Hornstein _et al_. (1943) as cited by Bennion (1972) suggests that a greater tenderizing power exists in unsaturated liquid fats which is due to a greater spreading of the liquid fat over the flour surface because of the attraction of the double bonds. The olein fraction is the most unsaturated of the shortening samples (Bussey _et al_.,

1981) which could explain the increased tenderness for the olein fraction. The original tallow cake took the most force to compress 10.88 lb, but no significant differences existed in compressibility of the cakes. Moisture content of the products averaged approximately 70%, with no significant difference found among samples.

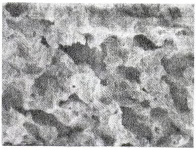
Texture of the cakes, as an indication of cell size, uniformity and thickness of walls was determined using SEM (Figure 14). As can be seen, the cake prepared with hydrogenated vegetable shortening (Crisco) has larger air cells, with the tallow cakes looking very much alike. The cake prepared with Crisco has an average cell diameter of 400 μ, whereas the tallow cakes has an average cell diameter of 300 μ. This difference could be attributed to dispersion of the fat in the cake system and the emulsifier present. Unsaturated fatty acids cover greater areas per molecule than saturated fatty acids, and thus their dispersion is greater (Bennion, 1972). The commercial vegetable shortening contains more saturated fatty acids than the tallows (Home and Garden Bulletin No. 72; Bussey et al., 1981), which could account for the decreased dispersion and the resulting increase in cell diameter. The emulsifier added to the tallow cakes in this system, Vanall, contains a variety of different emulsifiers (Sorbitan monostearate, glycerol monostearate and polysorbate 60) each of which have different emulsifying characteristics in the batter system.



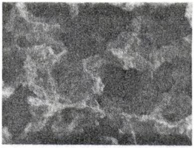
25° C solid fraction
beef tallow



35° C olein fraction
beef tallow



original beef tallow



Crisco

Figure 14. Scanning electron micrographs of white layer cakes prepared with various shoternings.

Crisco, in contrast, contains only mono and diglycerides. This difference in type of emulsifier present in the cake system (and possibly amount) could have caused the air cell size variation. Also, the increase in volume of the control cake, though insignificant, could have lead to this effect.

The polymorphic form of the fat is also important in determining the batter characteristics and final cake grain and texture. Original tallow and fresh hydrogenated vegetable oils both exhibit the β' polymorph (Hoerr, 1960). No research to date has been reported on the crystalline habits of beef tallow fractions. It is assumed that both the $35^{\circ}C$ olein sample and the $25^{\circ}C$ solid fraction fat also exhibit the β' polymorph due to the extreme stability of the β' crystals found in original beef tallow (Hoerr, 1960). It is possible that the solid fraction is not as β' stable due to the increased amount of solid components present. The presence of SDS might also cause crystal modification (DelVecchio, 1975). The β' crystalline structure of a shortening is necessary to provide a cake of high quality (Moncrieff, 1970). The β' fats incorporate numerous, fairly small air bubbles in the batter, the intermediate fats produce a somewhat coarser air distribution and the β fats produce relatively few large air bubbles (Hoerr, 1960). Since the texture, by SEM, displayed little difference between tallow samples and the volume and the tenderness of the baked products were consistent, this polymorphic

transformation is unlikely.

Sensory Evaluation

Sensory evaluation of the baked product revealed that all cakes performed equally well with significant differences noted only for grain (Table 13). The cake prepared with original tallow had a poorer grain, rating 13.2 out of a possible 15, with the other samples rating 14.1, 14.6 and 14.4 for the 25^{o}C solid tallow fraction, 35^{o}C olein tallow fraction and control cake, respectively. This grain evaluation relates to the texture evaluation in determining the crumb characteristics. The opposition of results expressed could be due to the small sample size utilized in the texture evaluation and the inexperience of taste panel members.

The cake prepared with the 35^{o}C olein fraction tallow had the lowest flavor rating of 6.8 followed by the cake prepared with the 25^{o}C solid fraction with a rating of 7.3, the original tallow cake with a score of 7.4 and the control cake with a score of 8.8. While differences in flavor scores were noted, these were not significant at the 95% level. All cakes were rated as equally acceptable by panel members obtaining a total score in excess of 84 out of a possible 100 points. The tallow cakes flavor scores in this investigation are somewhat lower than those reported by Bundy _et al_. (1981). Bundy and coworkers (1981) reported

Table 13. Sensory scores of AACC White Layer Cakes prepared with commercial shortening original tallow, and two beef tallow fractions.

Characteristics[A]	maximum possible	commercial shortening[B]	original tallow	fractions 25°C, solid	fractions 35°C olein
Cells					
uniformity	10	$7.7^a \pm 0.8$	$7.3^a \pm 0.5$	$7.8^a \pm 1.7$	$7.3^a \pm 0.6$
size	10	$8.5^a \pm 1.0$	$8.3^a \pm 0.4$	$8.4^a \pm 0.8$	$8.4^a \pm 0.3$
thickness of walls	10	$8.8^a \pm 0.2$	$8.4^a \pm 0.2$	$9.0^a \pm 0.6$	$8.6^a \pm 0.6$
Grain	16	$14.4^a \pm 0.4$	$13.2^b \pm 1.1$	$14.1^a \pm 0.5$	$14.6^a \pm 0.3$
Texture					
moistness	10	$8.9^a \pm 0.4$	$8.7^a \pm 0.2$	$8.5^a \pm 0.6$	$9.3^a \pm 0.1$
tenderness	14	$12.5^a \pm 0.8$	$12.1^a \pm 0.6$	$12.6^a \pm 0.3$	$13.2^a \pm 0.3$
softness	10	$8.9^a \pm 0.8$	$8.8^a \pm 0.3$	$9.3^a \pm 0.4$	$9.6^a \pm 0.2$
Crumb Color	10	$9.8^a \pm 0.2$	$9.7^a \pm 0.3$	$9.7^a \pm 0.4$	$9.9^a \pm 0.2$
Flavor	10	$8.8^a \pm 0.4$	$7.4^a \pm 0.9$	$7.3^a \pm 1.4$	$6.8^a \pm 0.8$
TOTAL	100	$87.7^a \pm 3.4$	$84.2^a \pm 2.2$	$87.1^a \pm 2.4$	$87.7^a \pm 1.1$

[A] based on A.A.C.C. Method 10-91, scale for four replications; eight member taste panel.

[B] Crisco, hydrogenated shortening (soy and palm oils); Proctor and Gamble

[abc] means followed by same letter indicate no significant difference ($p<0.05$)

flavor scores of 8.9 and 8.1 for the 25°C solid tallow fraction cake and 35°C olein fraction cake, respectively. Both investigations utilized the same lot of deodorized beef tallow, although Bundy and coworkers' (1981) investigation was conducted approximately twelve months earlier. During the storage (4°C) of the tallow a stronger flavor could have developed, which could have resulted in the flavor scores experienced. The discrepancy in flavor scores also could be due to the individual panel members acuity for the tallow taste. A larger panel size in both of these investigations would have been preferred.

Tallow Variability

Beef tallow is not a uniform component but depends on the cattle from which it is obtained (Paul, 1972). The composition of the fat on any particular animal is affected by a variety of intrinsic and extrinsic factors. The difference can be attributed to breed, sire, sex and age of the animal and treatment influences of feed, exercise and stresses, as well as many other environmental conditions (Paul, 1972; Wilson, 1960). The possibility for larger variation in tallow characteristics exists which could have different functional properties in food systems.

In the course of this investigation, four different tallow samples were utilized from three different processors over a period of one year. Bussey *et al.* (1981), Bundy

et al. (1981), DeFouw et al. (1981) and Ryan (1982) all utilized the same shipment of tallow from Stadler and Company, Cleveland, Ohio. This shipment (2x400 lb drums) was received in summer, 1979. The tallow used in the preparation of white layer cakes also came from this source. Tallow samples were also received from Bungee Edible Oil Corporation, Kankakee, Illinois, and Iowa Beef Processors, Nebraska. Samples were received in 50-60 lb drums during both winter and summer months. It was observed that the samples received during the winter and early spring months would not fractionate following the given procedure (Bussey et al., 1981) and consequently appeared "harder" than the tallow received from Stadler and Co. It is speculated that feed variation could account for this observed difference.

Early work on the effect of feed on body deposition fat in the bovine refutes the feed influence. Severn (1951) states that the body fat of cattle unlike that of swine is affected relatively little by the feed of the animal. Severn (1951) also reported that the environment of the animal appears to influence the composition of the fat, with warm temperatures tending to reduce the unsaturation.

More recent work has looked at the carcass fat from cattle fed both high and low ratio fat diets, as well as different sources of fat. Dryden and coworkers (1973) reported that the type, and to a lesser extent, the amount of fat fed the bovine was effective in altering the type of fatty acids deposited in the subcutaneous fat of the tail head region. Dryden and Marchello (1973) found that diets containing safflower oil at 6.0% caused the depot fat to be more unsaturated than the diets supplemented with 6.0% animal fat in the bovine. Johnson and McClure (1972) reported that the addition of hydrogenated fat to the diet of the ruminant increased the proportions of oleic acid and decreased the polyunsaturated acids. In general, the addition of unsaturated dietary fats results in an increase in the degree of unsaturation of fatty acids in depot fat (Dryden and Marchello, 1973; Dryden et al., 1973), whereas the addition of highly saturated animal fat has very little effect on the fatty acid composition of the body fat stores (Dryden et al., 1973; Dryden and Marchello, 1973; Johnson and McClure, 1972).

Cattle in the United States are generally grain fed (Swern, 1964). No mention is made of the availability of the cattle to graze, but it is speculated that grazing is occurring in the warmer months. The effect of grass vs corn feeding is speculated as the cause for the variability of tallow samples used in this investigation.

Much of the success with the fractional crystallization process of beef tallow has taken place in Australia (Haraldson, 1974). It is speculated that grazing of cattle is common in Australia and that the ratio of unsaturated to saturated fats is favorable for the fractional crystallization process.

In an attempt to substantiate this hypothesis, fatty acid profiles were compared for different lots of tallow (Table 14). It was found that there was a greater difference between the values reported for the same lot of tallow (Bussey *et al.*, 1981; DeFouw, 1981) than fatty acids from different lots of tallow.

Table 14. Fatty acid composition of original beef tallow from different sources and different seasons.

Fatty acid	Stadler and Co. [1]	Stadler and Co. [2] (summer)	Iowa Beef Processors (winter)	Bunge oil (summer)
$C_{14:0}$	3.6	3.7	a	a
$C_{16:0}$	24.1	29.16	26.58	27.4
$C_{16:1}$	6.6	4.56	4.29	4.4
$C_{18:0}$	13.7	17.83	19.27	18.9
$C_{18:1}$	50.1	44.75	47.33	46.8
$C_{18:2}$	-	tr	1.40	2.4
$C_{18:3}$	0.4	-	1.12	-

[1]reported by Bussey *et al*. (1981)

[2]reported by DeFouw *et al*. (1981)

[a]not reported

SUMMARY AND CONCLUSIONS

The functionality and utilization of beef tallow fractions obtained by aqueous fractionation of tallow was investigated in a three phase study.

The quality of deep fat fried doughnuts was found to be equally acceptable using original beef tallow or either the 20^{o} and $30^{o}C$ olein fractions. The doughnuts fried in a commercial soybean oil was found to be less acceptable than any of the doughnuts fried in the tallow frying media principally due to the low sensory flavor and fat absorption scores. Objective measurements on the oil and substrate revealed a low degree of oil degradation in the eight intermittent fryings of doughnuts, possibly due to the fresh fat added back to the fryers.

Batter coated chicken wings were fried in 20^{o} and $30^{o}C$ olein fractions, original tallow and a commercial, soybean oil. The acceptability of the chicken wings was not found to be influenced by the original tallow or tallow fractions as frying media. Original beef tallow and tallow fractions were found to be more acceptable frying media than the commercial soybean oil in the deep fat frying of batter coated chicken wings. Objective measurements on the oil and substrate revealed a low degree of oil degradation in the twelve intermittent fryings of chicken possibly due to the fresh fat added back to the fryers.

The quality of A.A.C.C. White Layer Cakes was not adversely affected by the utilization of beef tallow as the shortening constituent when emulsifier was present. Significant deficiencies existed in the batter aeration properties when original tallow or solid or olein fractions were utilized, but these deficiencies were not evidenced in the baked product. Dispersibility of the fat in the cake system was found to be greater and more uniform for all the tallow variables than the commercial shortening, possibly due to the amount and type of emulsifier present in this system.

The fractional crystallization process is not beneficial in producing fats and oils from beef tallow with equivalent acceptability to a commercial control. Original beef tallow has shown acceptability as a deep fat frying medium for doughnut and batter coated chicken wings and as a shortening in the preparation of white later cakes.

PROPOSALS FOR FURTHER RESEARCH

In the course of this investigation several questions were raised which need addressing. These include:

1. Feeding studies with cattle to determine if the degree of change in body deposition fat affects the fractional crystallization procedure.
2. Pilot plant operations to investigate the large scale operation of deep fat frying using original beef tallow and/or beef tallow fractions as in a continuous potato chip frying operation.
3. Cost analysis investigation of the efficiency of the fractionation procedure including energy, transportation, manpower and raw product cost among others.
4. Determination of the polymorphic structure of the various tallow fractions and their use in shortening and margarine preparations.
5. The cholesterol content of the various solid and olein fractions and their affect on human health.

APPENDICES

Appendix I

Doughnut Score Card

Sample #__________________ Name____________________________

Date____________________________

	Points	Score
A. Tenderness		___
very tender	10	
moderately tender	8	
tender	6	
slightly tough	4	
very tough	2	
B. Fat Absorption		___
no fat absorbed	10	
slight fat absorption	8	
moderate fat absorption	6	
great fat absorption	4	
fat absorbed entirely	2	
C. Crust Color		___
optimum color - golden brown	10	
slightly too light or too dark	8	
moderately too light or too dark	6	
very light or very dark	4	
pale or burned	2	
D. Flavor		___
like very much	10	
like moderately	8	
neither like nor dislike	6	
dislike moderately	4	
dislike very much	2	

Comments:

Appendix II

Chicken Score Card

Sample #__________________ Name__________________________
Date__________________________

	Points	Score
A. Crust Color		___
optimum color - golden brown	10	
slightly too light or too dark	8	
moderately too light or too dark	6	
very light or very dark	4	
pale or burned	2	
B. Fat Absorption		___
no fat absorbed	10	
slight fat absorption	8	
moderate fat absorption	6	
great fat absorption	4	
fat absorbed entirely	2	
C. Tenderness		___
very tender	10	
moderately tender	8	
tender	6	
slightly tough	4	
very tough	2	
D. Flavor		___
like very much	10	
like moderately	8	
neither like nor dislike	6	
dislike moderately	4	
dislike very much	2	

Comments:

Appendix III

Layer Cake Score Card

Sample #________________ Name________________________

Date________________________

	Points	Score
A. Cells (30 points)		
1. Uniformity (10 points)		
(a) Even (normal)	10	
(b) Slightly uneven	6	___
(c) Uneven	2	
2. Size (10 points)		
(a) Dense (normal)	10	
(b) Close	8	
(c) Slightly open	6	___
(d) Open	4	
3. Thickness of Walls (10 points)		
(a) Thin (normal)	10	
(b) Slightly thick	6	___
(c) Thick	2	
B. Grain (16 points)		
1. Silky (normal)	16	
2. Harsh	10	___
3. Coarse (cornbread)	8	
C. Texture (34 points)		
1. Moistness (10 points)		
(a) Gummy	6	
(b) Moist (normal)	10	
(c) Slightly dry	8	___
(d) Dry	4	
2. Tenderness (14 points)		
(a) Very tender (normal)	14	
(b) Tender	12	
(c) Slightly tough	10	___
(d) Tough	4	
3. Softness (10 points)		
(a) Soft (normal)	10	
(b) Slightly firm	8	
(c) Firm	4	___

Appendix III

(cont'd.)

D. Crumb Color (10 points)

1.	Acceptable	10
2.	Slightly unacceptable	5
3.	Unacceptable	0

E. Flavor (10 points)

1.	Normal (no off flavors)	10
2.	Slight off flavor	5
3.	Unacceptable (off flavors present)	0

Appendix IVa. Analyses of variance of physical characteristics of doughnuts deep fat fried in commercial frying oil, original tallow and two beef tallow fractions.

Source	df	Mean Squares									
		Doughnuts						Oil			
					Color				Color		
		tenderness	fat absorption	moisture	L	a	b	Viscosity	L	a	b
Total		-	-	-	-	-	-	-	-	-	-
Variable		436.76	13.99	1.78	3.58	0.14	2.77	42.64	6.32	2.94	14.70
Replication		529.42	4.09	1.57	1.44	1.26	2.38	3.52	2.11	0.90	2.07
Within		63.49	11.63	0.72	4.44	0.98	1.99	1.87	1.50	0.57	0.37

Appendix IVb. Analyses of variance of sensory evaluations of doughnuts deep fat fried in commercial frying oil, original tallow and two beef tallow fractions.

Source	df	Mean Squares			
		tenderness	fat absorption	crust color	flavor
Total		-	-		
Variable		0.19	0.92	0.25	5.73
Replication		0.10	0.07	0.32	0.22
Within		0.15	0.19	0.25	0.40

Appendix IVc. Analyses of variance of physical characteristics of chicken wings deep fat fried in commercial frying oil, original tallow and beef tallow fractions.

Source	df	Mean Squares					
		Chicken		Oil			
					Color		
		fat absorption	moisture	viscosity	L	a	b
Total	15	-	-	-	-	-	-
Variable	3	23.60	35.17	101.97	6.01	5.80	4.56
Replication	3	1.12	19.48	2.97	0.97	1.37	0.65
Within	9	12.03	21.06	2.39	0.38	1.10	0.41

Appendix IVd. Analyses of variance of sensory evaluations of chicken wings deep fat fried in commercial frying oil, original beef tallow and two beef tallow fractions.

Source	df	Mean Squares			
		tenderness	fat absorption	crust color	flavor
Total		-	-	-	-
Variable		0.36	0.81	0.06	2.35
Replication		0.81	0.36	0.76	0.16
Within		0.18	0.16	0.43	0.13

Appendix IVe. Analyses of variance of physical characteristics of A.A.C.C. White Layer Cake prepared with commercial shortening, original beef tallow, and two beef tallow fractions.

Source	df	Mean Squares									
		Butter		Cake							
		specific gravity	viscosity	volume	tenderness	compressibility	moisture	volume index	symmetry index	uniformity index	shrinkage
Total		-	-	-	-	-	-	-	-	-	-
Variable		0.013	298.68	1422.38	0.182	5.664	0.00	19.063	9.50	0.729	0.012
Within		0.002	34.67	524.48	0.030	4.200	0.00	8.146	3.71	3.350	0.020

Appendix IVf. Analyses of variance of sensory scores of A.A.C.C. White Layer Cakes prepared with commercial shortening, original tallow, and two beef tallow fractions.

Source	df	Mean Squares									
		Cells			Grain	Texture			Crumb Color	Flavor	Total
		uniformity	size	thickness of walls		moistness	tenderness	softness			
Total	15	-	-	-	-	-	-	-	-	-	-
Variable	3	2.26	0.01	0.24	1.57	0.44	0.81	0.56	0.01	2.81	11.21
Within	12	54.68	0.08	0.23	0.40	0.14	0.26	0.21	0.08	0.84	5.83

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