



Functional Properties of Cottonseed Oil

Frying Oil Characteristics

Deep-fat frying and pan-frying are two major methods of cooking foods. Pan-frying uses small amounts of oil to quickly seal in the natural juices of meats and vegetables. Light-colored, mild-tasting oils are preferred. Vegetable oils spatter and smoke less than margarine or butter. Deep-fat frying surrounds a food with hot (180° C or 375° F) oil and causes more chemical changes in fats than any other method. Prepared food manufacturers and restaurants employ deep-frying extensively, but many consumers also use deep-fat frying at home.

Frying Effects

Frying fats play many roles in producing a variety of quality characteristics in fried foods. The fats act as a medium to transfer heat rapidly, producing desirable flavors, aromas and colors due to various chemical reactions. These changes have been well summarized. Reprinted from Nawar (1985), by courtesy of Marcel Dekker, Inc.:

Water is continuously released from the food into the hot oil. This produces a steam-distillation effect, sweeping volatile oxidation products from the oil. The released moisture also agitates the oil and hastens hydrolysis, resulting in increased amounts of free fatty acids. The blanket of steam formed above the surface of the oil may reduce the amount of oxygen available for oxidation.

During frying, volatiles (e.g., sulfur compounds and pyrazine derivatives from potato) may develop in the food itself or from the interaction between the food and the oil.

Foods absorb varying amounts of oil from deep-fat fryers (potato chips contain approximately 40% fat), resulting in the need for frequent or continuous addition of fresh oil. In continuous fryers, this results in the rapid attainment of a steady-state condition for oil properties.

The food itself releases some of its endogenous lipids into the fryer (e.g., chicken fat). The oxidative stability of the new mixture may be different from that of the original frying fat.

The presence of food causes the oil to darken at an accelerated rate.

Fat Absorption by Foods

Fritsch (1981) has reviewed the changes that occur as a frying fat is heated. The dynamics are summarized in Figure 5-1. The amount of fat absorbed by a food depends on several factors including oil temperature, length of frying time, and the surface area and the thickness of the food. When french-fried potatoes were fried at 180° C for one to ten minutes, the cooking oil remained on the surface and penetrated only the

first few cell layers (Keller, et al, 1986). Since potato chips are sliced thin, they pick up more oil than other fried potato products on a weight basis. Potato chips absorb 10-15% less fat when they are fried in an oil that is a liquid at room temperature instead of a fat that is solid at room temperature, partly because the oil drains better from the chips (Matz, 1984). A survey of deep-fat fried foods and their fat content was made by Smith et al. (1985) Figure 5-2.

Sensory Qualities of Frying Oils

Flavor Quality and Intensity Ratings

The flavor and odor of a cooking oil are the most important indicators of quality. An oil with poor taste and odor will be quickly rejected by consumers. The science of sensory or organoleptic evaluation is complex, and the myriad of chemical compounds which contribute to the sensory quality of an oil complicates scientific analysis. The American Oil Chemists Society has developed flavor quality and intensity scales to be used in the evaluation of oils (Warner, 1985).

Warner (1988) has characterized the flavor descriptions of several vegetable oils (Table 5-1). These descriptions change

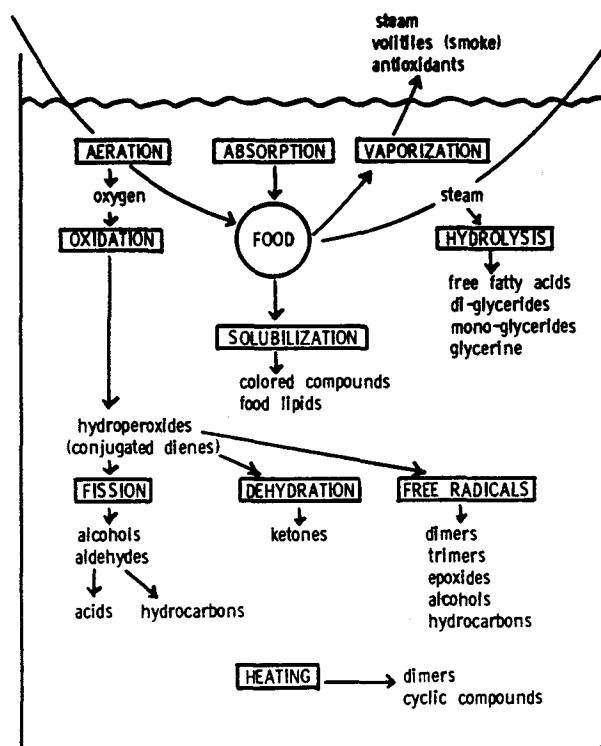


FIGURE 5-1. CHANGES DURING FAT FRYING (From Fritsch, 1981)

Table 5-1. Characteristic flavor descriptions of vegetable oils^a (From Warner, 1988)

Processing Step & Storage	Vegetable Oil			
	Soybean	Canola	Sunflower	Cottonseed
Refined, bleached (diluted 5:95 in deodorized oil)	grassy/hay grassy/green beany	cabbage sulfur grassy/ green	pine/cedar weedy acid	weedy sulfur woody
Deodorized 0-Time	nutty, buttery	nutty, buttery	nutty, buttery	nutty, buttery
Storage in dark	buttery, rancid, painty, grassy	cabbage, rancid, painty, fishy	weedy, rancid, burnt, nutty	waxy, rancid
Storage in light	"light struck" grassy, sour buttery	buttery, grassy metallic	stale, sour	"light-struck"

^aAll deodorized oils contained 100 ppm citric acid.

depending upon the level of processing and the length of storage of the oils. Refined, bleached, deodorized cottonseed oil has a flavor described as "nutty/ buttery/ waxy".

Volatiles Responsible for Flavors and Odors

Food scientists can detect chemicals which contribute to the flavor and odor of oils, but testing alone cannot show how, and in what proportion the compounds contribute to the sensory characteristics. Numerous low molecular-weight volatile compounds have been identified in fresh and in heated frying oils (Min and Smouse, 1985). Aldehydes and ketones dominate the volatiles responsible for flavors and odors. Hexanal has been associated with flavor scores in cottonseed oil. Warner, et al., (1978) indirectly correlated hexanal levels with flavor scores for cottonseed oil containing citric acid or Tenox 6 (Eastman Chemical Products, Inc.) antioxidant. Higher levels of pentanal and hexanal were not associated with proportionate reductions in flavor scores. Pentane and hexanal were the major volatiles found in the headspace of cottonseed, corn, safflower, and sunflower oils (Snyder, et al, 1985). The volatiles increased as the amount of peroxides in the oils increased.

The development of the above flavor compounds may depend upon the presence of linoleic acid, the predominant fatty acid in cottonseed. May, et al (1978) reported that some unsaturated lactones contribute to deep-fat fried flavor. These compounds appeared to form after vegetable oils were heated. Sensory panelists preferred chips that had been coated with cottonseed oil containing 2.5 ppm 4-hydroxyl-3-nonenic acid lactone to chips coated with bland cottonseed oil.

Several known products of lipid oxidation were added to cottonseed oil to determine their effects on room odor by

Evans, et al. (1972). Only 2,4-dodecadienal added at a concentration of 200 ppm caused a significant reduction in odor score compared to the control cottonseed oil. The researchers concluded that these chemicals would have to be present at levels about 100 times greater than their taste thresholds to be detected in room odors.

Cottonseed Oil Flavor

Cottonseed oil is well-known for its bland, slightly nutty, taste. For this reason, when used with certain foods, cottonseed oil is often used as the standard against which other oils are compared for odor and flavor (May, et al., 1978; Robertson, et al., 1978). The popularity of beef tallow for its flavor contribution to french fries has increased the use of tallow-cottonseed oil blends because cottonseed oil facilitates handling characteristics of the higher melting tallow, raises the proportion of unsaturates and its mild taste enhances the tallow flavor (Fitch, 1987). Products such as canned shoestring or julienne potatoes have the potential for remaining on store shelves longer than bagged potato chips. For this reason they are fried in an oil with high resistance to oxidation to prevent the development of off-flavors (Weiss, 1970). Cottonseed oil that has been hydrogenated to an IV of 70-75 is ideal for these kinds of products.

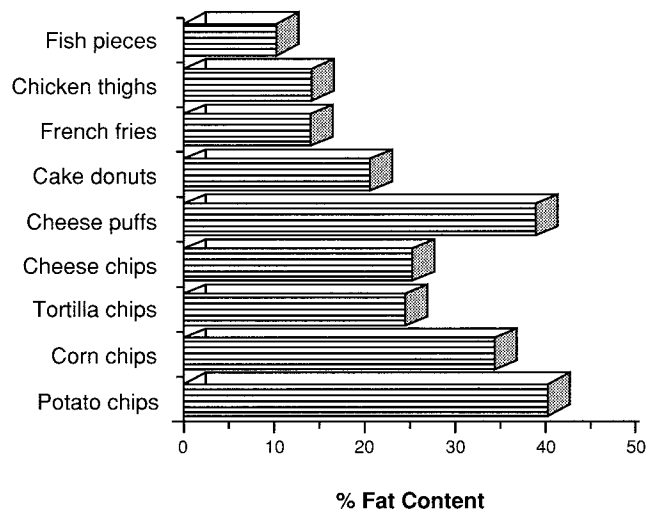


FIGURE 5-2. MEAN LIPID CONTENT (g/100g EDIBLE PORTION) OF SELECTED SNACK AND FAST FOODS. (From Smith et al, 1985)

Cottonseed Oil Flavor Compared to Other Oils

One problem in determining the effect of different frying fats and oils on the sensory quality of foods is the contribution of the foods' own flavor and aroma. Blumenthal and co-workers (1976) resolved this problem by using cotton balls in their research. When moistened, the cotton balls were similar in water content to potatoes, but had the advantage of being inert. The odors and flavors of cotton balls fried in this kind of test were derived from the cooking oil only. The strength, or intensity, and the pleasantness of the odor and flavor were ranked for corn, cottonseed, peanut, and soybean oils. Three different hydrogenated soybean oils were evaluated with iodine values of 70, 89, and 115. Corn oil had the highest scores for pleasantness and the lowest strength of odor and flavor scores. The odor and flavor of the cottonseed oil was found to be more pleasant than those of the peanut and soy oils. The flavor pleasantness score for the cottonseed oil was nearly double the rating for the soybean oil with an iodine value of 115. The hydrogenated soybean oils had the highest scores for strength and the lowest scores for pleasantness, indicating that strong organoleptic characteristics are not always desirable ones. These researchers also found some correlations between the gas chromatographic profiles and the sensory scores for these oils, suggesting that various volatile compounds are responsible for odors and flavors. Another study by Warner (1988) evaluated the frying stability of cottonseed, soybean, low erucic acid rapeseed, sunflower, and high-oleic sunflower oils and found that the cottonseed and high-oleic sunflower oils produced much less room odor when heated. A mild odor is an indication of quality (Table 5-2). Cottonseed and other oils which contain palmitic, stearic and oleic acids in large amounts are more stable because

Table 5-2. Heated oil evaluation (From Warner, 1988)

Oils	Room Odor Scores ^a	Descriptions
Soybean	5.9	Fried food, fishy, acrid
Canola	5.3	Fried food, fishy, acrid
Sunflower	4.8	Fried food, acrid, aldehyde
Cottonseed	3.7	Fried food, waxy, plastic
High oleic sunflower	3.6	Fried food, waxy, plastic

^aScores based on 0-10 scale with 0 = none, 10 = strong.

they are "naturally hydrogenated." That is, even though extremely low levels of saturates are seen as a nutritional virtue, the 26% level of saturated fatty acids in cottonseed oil does confer a natural stability to the oil. Indeed, cottonseed oil can be used in many products where there is a desire to avoid the use of hydrogenated oils for purposes of keeping the term off of a product label. Also, the cottonseed oil does not have the "hydrogenated" flavor.

Characteristics of Cottonseed Oil Blends

Blending With Canola Oil

Fresh oils have virtually no odor. During frying, odors develop from the heating of the oil and from the food being fried and this may limit the use of oils in some situations (Mounts, 1979). Soybean and canola, or low erucic acid rapeseed (LEAR) oils, in particular, develop objectionable fishy odors during frying due to their high linolenic acid contents. Odor intensity and the production of volatiles were reduced in heated LEAR oil when cottonseed oil was added to dilute the linolenic acid of the LEAR oil (Durance, 1986). When stored at 40° C, used cottonseed oil had less rancid odor than did used canola oil (Vaisey-Genser and Eskin, 1987). The rancid odor scores for used canola oil stored at 40° C and in the presence of 250 foot-candles of light were also higher than those for cottonseed oil, but the difference between the two oils were not as great.

Blending with Soybean Oil

Blends of cottonseed oil with soybean oil, ranging from 0-100%, were evaluated by a sensory panel conducted by Evans et al (1972), for room odor intensity value and pleasantness score. Fishy and rancid odors were higher in the blends containing more soybean oil. The highest preference scores were given to the oils containing 75% or more cottonseed oil. Lesieur (1976) even suggested that soy and rapeseed oils be used cold, in salads for example, because of their objectionable odors and flavors during frying, which was related to the presence of linolenic acid in these oils.

Effects of Additives on Flavor and Odor

The addition of antioxidants to oils has little effect on the room odor produced when the oils are heated. While antioxidants slow the oxidation reaction, they do not eliminate oxidation. Antifoaming agents such as silicones do improve room odor scores (Evans, et al., 1971) because the silicone floats on the oil surface and acts as a barrier to prevent oxidation. Soybean oil with silicone added had a room odor score of 4.9, while the same oil without additives had a room odor score of one point lower and more intense rancid and fishy odors (Mounts, 1979). Hydrogenation improves the oxidative stability of vegetable shortenings but does not appear to cause better odor scores (Evans, et al., 1972).

Rancidity

Both hydrolytic and oxidative rancidity of fats and oils results in the formation of many off-flavors and odors. In addition, when fats are heated thermal decomposition occurs and the rate of rancidity increases. Some of the changes in oils that occur with repeated use are listed in Table 5-3.

Hydrolytic Rancidity

During hydrolysis, water is added to the ester bonds of a triglyceride molecule. The fatty acids are broken from the glycerol "backbone," are replaced by hydroxyl groups and

Table 5-3. Changes in used frying oils

<u>Due to Hydrolytic Rancidity</u>	
Increased Free Fatty Acids	
Decreased Smoke Point	
<u>Due to Oxidative Rancidity</u>	
Increased Peroxide Value	
Decreased AOM	
Decreased Iodine Number	
<u>Due to Thermal Decomposition</u>	
Increased Viscosity	
Increased Foaming	
Darkened Color	
Gum Formation	

allowed to become free fatty acids. These free fatty acids may be measured as an indication of the degree of hydrolysis that has occurred.

Hydrolysis is dependent upon the availability of water and increases when the oil or fat is heated. However, water does not have to be present in the oil since it can be supplied by the foods being fried. Small amounts of water in cottonseed oil may not significantly affect the rate of hydrolysis, since water can be formed from products of oxidation and free radicals (Peled, et al, 1975). Perkins and Van Akkeren (1965) simulated the effect of frying a food with a high water content by constantly dropping water into heated cottonseed oil. A total of 54.14 liters of water was added to 9.0 liters of oil during the study. The free fatty acid content increased by seven-fold over a 188-hour heating period. The iodine value of the oil also decreased in this time.

Oxidative Rancidity

Autoxidation of unsaturated fats can result in the production of various aldehydes, ketones and other compounds. Some of these compounds are inert, while others are responsible for the characteristic odors and flavors, both pleasant and unpleasant, of fried foods. Polyunsaturated fatty acids are more susceptible to this type of rancidity because their double bonds are very reactive. To inhibit oxidation, some oils are packaged with nitrogen gas in the head space of the container which acts to exclude air. Metals, light, and plant pigments act as catalysts for oxidation, so they should be prevented from coming in contact with oils.

Antioxidants

The stability of oils, including cottonseed oil, can be protected by the addition of antioxidants. The various commercial antioxidants act in different ways to prevent oxidation. The tocopherols, butylated hydroxy anisole (BHA), and butylated hydroxy toluene (BHT) scavenge for highly reactive free radicals that initiate oxidation. Citric acid chelates, or ties up, metal ions. Ascorbic acid and its fat-soluble form, ascorbyl palmitate, absorb oxygen that may be in the oil. The

FDA permits the addition of up to 0.01% of any one synthetic antioxidant, and up to 0.02% of any combination of antioxidants. Many antioxidants have a synergistic effect and together are more effective than if added alone. While cottonseed oil contains natural tocopherols, commercial antioxidants may be added to the refined oil. Du Plessis et al. (1981) added TBHQ (tertiary butylated hydroquinone) to cottonseed and peanut oils and measured the loss of the TBHQ and the alpha- and gamma- tocopherols that were already in the oils. The cottonseed oil retained most of its antioxidants during the 120-hour frying period, but the peanut oil lost about half of its tocopherols and TBHQ (Figure 5-3).

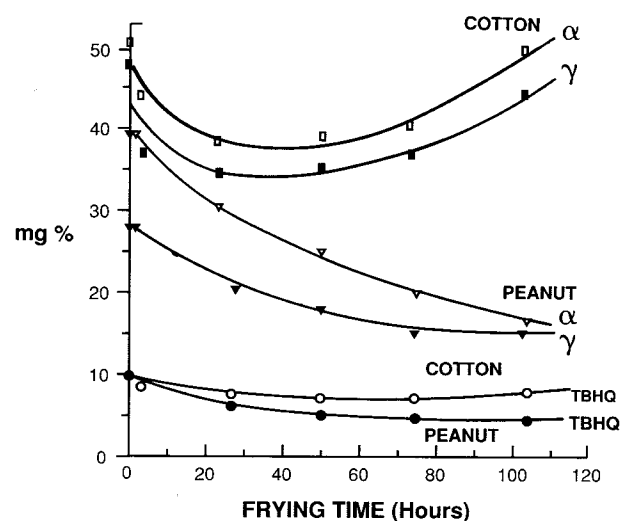


FIGURE 5-3. ALPHA-, AND GAMMA-TOCOPHEROLS AND TBHQ CONTENTS OF PEANUT AND COTTONSEED OILS AS INFLUENCED BY FRYING SOURCE (From Du Plessis et al, 1981)

Farang et al. (1989) have recently examined the ability of essential oils from thyme and clove to exhibit an antioxidant activity when added to cottonseed oil. They noted that clove oil at 1200 ppm protected cottonseed oil from oxidation for the same time period as BHT used at 200 ppm. Thyme oil was not quite as effective. Sensory evaluation tests of the two natural antioxidants indicated that the addition of thyme oil or clove oil to refined cottonseed oil at concentrations ranging from 50 to 1200 ppm did not affect the odor note of the cottonseed oil and were acceptable for consumption. Use of these natural antioxidants to suppress lipid oxidation in other oils as well as cottonseed oil may be attractive in some markets.

Thermal Effects

The heating of oils causes a complex series of reactions. Bonding between molecules occurs and branched, cyclic, and

polymerized compounds accumulate because their high molecular weights prevent them from boiling away. Paradis and Nawar (1981) suggested that these compounds may be better indicators of oil deterioration than polar or volatile compounds. Thermal breakdown products are associated with foaming, increased oil viscosity, darkened color, and gum formation in the oil.

Defining Oil Quality

Various oil quality attributes are required for the different types of foods and frying conditions in homes, restaurants, and food processing operations. Many factors contribute to the quality of an oil and Stevenson et al (1984) have published a list of specifications for frying fats (Table 5-4). Several important factors or parameters that define oil quality are discussed in the following sections.

Table 5-4. **Common Analytical specifications for deep frying fats and oils (From Stevenson et al. 1984)**

Parameter	Level in Unused Fat or Oil
Free fatty acid (FFA)	0.05-0.08% (or less)
Peroxide value	1.0 milliequivalent/kg oil
Iodine value	Varies with type of fat
Active oxygen method (AOM)	60 hrs. or greater if extended shelf life is required
Smoke point	200 C
Moisture	0.10%
Color	Light
Melting point	Varies with product being fried
Flavor and odor	Bland

Free fatty acids (FFA)

These compounds are products of the hydrolysis of triglycerides. Refining reduces the amounts of FFA in oil to 0.05% or less but FFA levels rise with use. Oils should be discarded when their FFA content reaches 1%, although some guidelines for the frying industry indicate that the oil should be discarded at 3.0% FFA.

Peroxide value (PV)

Peroxides are the first compounds formed during the oxidation of fats and oils. Since peroxides rapidly break down into other chemicals, their measurement does not indicate the total degree of oxidation by-products in the oil. PV is determined by titration as a measurement of oxidation and expressed in milliequivalents. Because peroxides decompose rapidly, an oil may have a low PV and still have severe oxidative damage.

Iodine value (IV)

The amount of unsaturation, or relative number of double bonds, is measured by the iodine value. A higher IV indicates more unsaturation. This basic parameter is commonly used in choosing oils.

Active Oxygen Method (AOM)

This is an accelerated storage test to determine the ability of an oil to withstand oxidation. Air is bubbled through the sample at a controlled rate of flow while the temperature is held at 97.8° C. Peroxide values are determined at intervals to estimate how many hours will be needed to attain a peroxide value of 100 Meq. AOM results are reported in hours.

Thiobarbituric acid (TBA) test

Products of the oxidation of unsaturated fats react with TBA to give a yellow-to-red color which can be measured spectrophotometrically. The use of this test in vegetable oils is controversial due to a number of interfering products.

Schaal oven test

This is another type of storage test for fats and oils. The samples are stored at 65° C and the degree of oxidation is measured by peroxide value or by odor or flavor.

Viscosity

Fresh oils become thinner when they are heated. As oils are heated over time, they become more viscous and flow more slowly. This change in viscosity may be measured with an Ostwald or Brookfield viscometer.

Color

Most oils have a pale yellow tint and are clear before they are used. During frying pigments from foods leach into the oil and polymers form due to the thermal decomposition of the oil. These factors cause the oil to darken. Many methods of color measurement exist. Samples may be compared to a color chart, or the Lovibond system of tinted glasses can be used. Oils that remain dark after filtration should be discarded.

Table 5-5. **Quality control tests for fats used in deep-frying operations (From Stevenson et al. 1984)**

Physical Tests	Chemical Tests
Without laboratory	With laboratory
Color	FFA
Foaming	TBA
Smoking	Peroxide value
Odor of frying fat	Iodine number
Length of fat use	AOM
Sensory evaluation of cooked product for flavor, odor and texture	Dienes
	Carbonyls
	Anisidine
With laboratory:	NUAF
Smoke point	Petroleum ether insolubles
Foam height	Total polars
Viscosity	
Color	
Refractive index	
Sensory evaluation of cooked product for flavor, odor and texture	



Some of the quality parameters may be measured on site in restaurants and institutions while others require laboratory facilities (Table 5-5). Trained personnel can recognize the changes in fats and oils and remove any that have been used for too long. Economics and quality controls must be balanced so that a fat that is still good will not be thrown away, or on the other hand, a damaged oil will not continue to be used.

Smoke Point

Since frying occurs at about 180° C, a smoke point above 200° C is desirable. Morgan (1942) determined the smoke points of several types of vegetable oils, both crude and refined which are presented in Table 5-6. In Figure 5-4, the smoke, flash, and fire points of cottonseed and peanut oils with 0-100% free fatty acids are illustrated.

Foaming

A fresh fat or oil in a properly cleaned fryer will rarely foam. When foods are placed into the hot fat, vigorous bubbling occurs as steam is generated. These bubbles quickly dissipate. Larger, more persistent bubbles are associated with foaming. The formation of polymers and the leaching of materials from the foods being fried are partly responsible for foaming. The presence of lecithins from eggs, and possibly other emulsifiers increase foaming. Moharram and Osman, (1982) noted that pronounced foaming developed after 30 hours of frying eggplant but no foaming occurred during the first 15 hours of cooking. Chang, et al. (1978) noted that an oil may contain considerable amounts of decomposition products when the foaming is severe enough for restaurateurs and food processors to discard the oil.

The most common anti-foaming agents added to fats are

the methyl silicones. These compounds can be lost during frying because they adhere to foods (Weiss, 1970). A high turnover rate of fat replacement can help minimize foaming by introducing more silicones and by diluting the fat breakdown products.

Filtering

During frying, small pieces of food or breading remain in the fat. These pieces accumulate near the bottom of the fryer or become suspended, and char, appearing on the food as black specks. Reduced smoke point and increased fat deterioration, particularly an increase in free fatty acids, are associated with the presence of food particles in the frying medium. Constant or daily filtration helps maintain the quality of the oil. Filter aids are added to oils to remove fines from suspension and build up the filter cake in order to trap additional particles. They may also improve the color of the oil. Potato

Table 5-6. Free fatty acids, smoke points, flash points, and fire points of several vegetable oils (From Morgan, 1942)

Oil	Type of Oil	Free Fatty Acids	Smoke Point Found	Flash Point	Fire Point
Cottonseed	Crude, hydraulic press	1.1	310	585	680
Cottonseed	Alkali refined	0.040	425	617	685
Cottonseed	Alkali refined, bleached	0.055	425	613	683
Cottonseed	Alkali refined, bleached, deodorized	0.040	428	613	680
Cottonseed	Alkali refined, bleached, deodorized	0.18	365	605	675
Cottonseed	RBD oil with IV-48.5	0.29	350	600	675
Corn	Refined and bleached	0.065	400	618	678
Soybean	Refined and deodorized	0.010	453	623	685
Olive	Edible grade	2.1	280	550	670

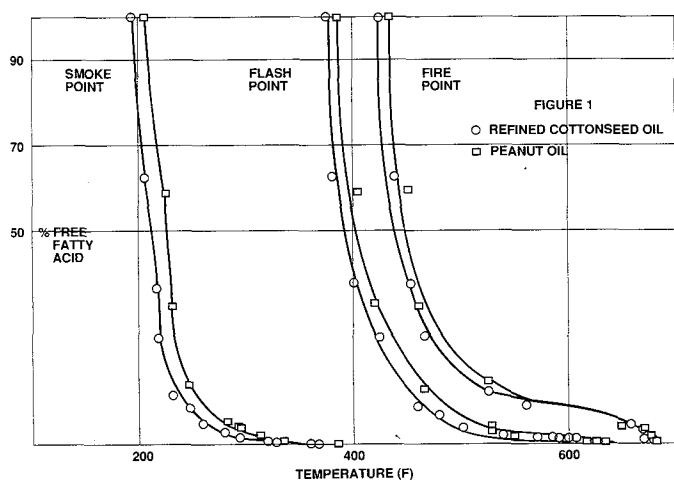


FIGURE 5-4. RELATIONSHIP BETWEEN FREE FATTY ACID CONTENT AND SMOKE, FLASH, AND FIRE POINTS OF COTTONSEED AND PEANUT OILS (From Morgan, 1942)

chippers can reduce oil consumption by 40% through consistent use of a filter system since less oil is discarded (Burns, 1986).

Adsorbent filter materials have large surface areas and can potentially increase the oxidative damage in an oil, especially if the filter involves aeration. Jacobson (1967) reported that the AOM stability of an oil bleached with 6% fuller's earth decreased from 120 hours to 30 hours. On the other hand, adsorbents can act to improve oil stability by reducing the amounts of free fatty acids, total polar materials, and color. Daily use of this type of filter aid may cause foaming (Mancini-Filho, et al., 1986).

What Happens To Cottonseed Oil Under Frying Conditions?

The importance of identifying the volatile decomposition products of an oil under deep fat frying conditions is paramount to maintaining taste and quality of products and getting the most fry life out of the frying medium. Chang and his colleagues at Rutgers University (Yasuda et al, 1968; and Reddy et al., 1968) have reported on both the acidic and non-acidic volatile decomposition products arising from the use of hydrogenated cottonseed oil in a deep fat fryer for up to 150 hours. They used the technique developed in their lab of frying moistened cotton balls at specified intervals to find out what happened to the fat in the fryer. The oil used was a refined, bleached and deodorized cottonseed cooking oil that had been hydrogenated to an iodine value of 69.2. The researchers identified 99 different acidic and nonacid volatile decomposition products that were formed in the simulated deep fat fryer experiment and tracked various oil parameters during the course of the trial. The free fatty acids went from 0.07% to 5.20% at 150 hours, and the peroxide number went from 1.15 to 1.65 Meq/kg at the end, but there was no foaming of the oil throughout the trial. The researchers conducted a parallel study using corn oil and made the observation that the cottonseed oil was more stable than the corn oil towards

autoxidation under frying conditions. The original research articles list the volatile products identified in this experiment.

The effect of chlorophyll in food products on cottonseed cooking oil when it is used to cook those foods was investigated by Taha et al. (1988). They noted that storing the oil with the chlorophyll-containing food for a month caused a shift in the absorption spectra of the cottonseed oil but that when the oil was later heated the spectra returned to that of the original food grade cottonseed oil. Peroxide values and UV-visible spectral values were presented by the investigators.

In 1986-87 cottonseed oil accounted for 2.5% of the oil used for baking and frying in the U.S.

Effects of Frying Foods on Oil Quality

Many studies have evaluated the effects of frying time, length of use, temperature, or type of food on the quality of cottonseed and other frying oils (Melnick, et al., 1958; Perkins and Van Akkeren, 1965; Walting and Zmachinski, 1970). Since linoleic acid is an essential fatty acid, Kilgore and Bailey (1970) measured the loss of linoleate from safflower, corn, and cottonseed oils and shortening. Four lots of a half-pound of potatoes were fried in each oil at 185° C for 12 minutes per lot. Over 70 hours ten pounds of potatoes were fried in each oil. The safflower oil lost the least linoleic acid, but it was the only oil protected by antioxidants. The cottonseed oil contained no additives, and about 12% of its linoleate was lost. The corn oil and shortening contained methyl silicones which retarded the rate of deterioration. The fat extracted from the fried potatoes contained smaller percentages of linoleic acid than the frying oils did. Winterized cottonseed oil used for frying tofu showed an increase in cyclic monomers from 0.26% up to 0.40% after 15 days of being heated to 177° C for five hours daily (Frankel, et al., 1984). These authors also noted that a comparison of used U.S. vs. Egyptian and Israeli frying oils indicated that the Middle Eastern oils were usually abused more than oils in the United States.

Cotton is a major crop in Egypt with domestic and U.S.-origin cottonseed oils being widely used as cooking oil. El-Sharkawy, et al. (1979) fried potato chips in cottonseed oil and observed the viscosity of the oil in which the chips were fried doubled during the study. After 10 hours, the changes in the chemical characteristics of the oil in this study showed that free fatty acids rose from 0.58 to 0.95%, the IV dropped from 119.8 to 89.1, and the peroxide value went from 19.04 to 38.89 Meq. Moharram and Osman (1982) have reported similar changes.

Potato and Corn Chips

Frying oil functions as both an ingredient and cooking medium for chips of all kinds. The storage and sensory quality of chips depends upon the oil used in frying. Along with quality aspects, cost must be considered as well since oils and shortenings account for 17-18% of the total cost of producing potato and corn chips (Anon., 1986).

Flavor

About 71% of the potato chips sold in the U.S. have no added flavors other than salt. Obviously, consumers prefer to taste the oil and potato flavors, not seasonings. Cottonseed oil may enhance the toasted corn flavor of corn chips, because this oil has a slightly nutty taste (Vandaveer, 1985). A sensory panel rated the odor and flavor of used cottonseed oil higher than those of peanut and soy oils, including hydrogenated soy oils (Blumenthal, et al., 1976). The carry-through of good flavor in used cottonseed oil to chips fried in it is important since frying oils are not replaced after every batch.

The processing of oil used in frying may contribute to the flavor of the chip as well. Vandaveer (1985) noted that chips fried in hydrogenated vegetable oils, particularly soybean, have a "hydrogenated" or "hardened" flavor compared to chips fried in nonhydrogenated oils. Only expert tasters may detect this flavor in fresh chips, but the flavor intensifies as the chips are stored and is noticeable to consumers. Soybean oil is frequently used by chippers despite its flavor problems. A blend of 15-25% cottonseed oil with 75-85% partially hydrogenated soybean oil can overcome the taste concern of soybean oil and possibly minimize oil expenses (Weiss, 1970).

Coconut oil is not used often for frying, but many snack food manufacturers coat extruded snacks with coconut oil to hold seasonings on the surface (Matz, 1984). While coconut oil is more resistant to oxidation, it is susceptible to hydrolytic rancidity and the free lauric acid that is produced gives an unpleasant soapy taste (Fritsch, 1981). Hydrogenated cottonseed oil has longer chain fatty acids which do not develop that kind of off-taste so it could be substituted for coconut oil in this application.

Flavor Stability

In general, off-flavors in chips are caused by oxidation products of the frying oil and the oil absorbed by the chips. Potato chips fried in soybean oil had increased volatiles and peroxide values that resulted from the oxidation of the frying oil (Min and Schweizer, 1983). The iodine and diene values of cottonseed oil are lower than for soybean oil (Table 5-7). These contribute to the longer shelf life of cottonseed oil. Cottonseed oil has adequate natural stability for many frying applications. (Vandaveer, 1985).

In another potato chip study, sunflower, cottonseed and palm oils were evaluated for their contribution to flavors. The chips fried in cottonseed oil were used as the standard for comparison with the other oils. Robertson and co-workers (1978) reported that the flavor of chips fried in the three oils deteriorated at the same rate during storage. During the first eight weeks of storage, cottonseed and sunflower oil-fried chips had better flavors than chips fried in palm oil. At 10 weeks of storage, all chips had poor flavor, but cottonseed-oil chips were given the smallest percentages of rancid and off-flavor responses. In an unpublished study at the University of Manitoba, used cottonseed frying oil stored in the dark was

Table 5-7. Frying oil characteristics (From Vandaveer, 1985)

Frying Fat or Oil	Iodine Value	Approx. Diene
Cottonseed	103-113	51
Soybean	125-138	53
Sunflower	110-128	46-72
Corn	110-128	55
Sesame	108-113	43
Peanut	84-102	26
Oleic safflower	85-93	14
Lard	58-68	11
Palm oil	45-55	10
Coconut	8-12	2
Processed soybean oil	86-103	23

more resistant to oxidation than similarly stored used canola oil. In the presence of light, however, the two oils showed the same patterns of rancid odor development (Vaisey-Genser and Eskin, 1987). Due to the stability of cottonseed oil, products which require longer shelf life are processed with cottonseed oil (Weiss, 1970).

Potato chips fried in either peanut or cottonseed oil were evaluated for flavor by a sensory panel and reported by Duplessis, et al., (1981). Over a 12-week period, the flavor scores decreased for chips fried in either oil. Although the chips fried in peanut oil received higher mean scores, chips from both oils were acceptable. The researchers doubted whether the taste differences would be apparent in seasoned chips.

While foods fried in cottonseed oil have a pleasant flavor, sometimes potato chips can develop an off-flavor, called "light-struck", because the taste only develops in cottonseed oil-fried chips that are exposed to light. Fan and co-workers (1983) determined that the formation of 1-decyne in the chips was responsible for the light-struck flavor. These researchers hypothesized that the cyclopropenoid fatty acids (CPFA) present in cottonseed oil became oxidized by light and 1-decyne was a product of that photooxidation. The presence of chlorophyll in the oil increases the amount of 1-decyne formed.

The production of 1-decyne can be minimized in several ways. CPFA are removed during the steam deodorization step of oil refining. Longer deodorization time reduced the CPFA content from 0.55% to 0.06% (Fan, et al., 1983). Specific catalysts (Feuge and Zarins, 1971) as well as selective hydrogenation (Zarins et al, 1982) can act to eliminate CPFA during refining. (Also see Chapter 4.) If deodorization modifications of cottonseed oil are not feasible, then another alternative for preventing the light-struck flavor is to prevent light from reaching the chips. After 40 days storage, potato chips packaged in opaque (Banlite) bags had one-fourth the 1-decyne content of chips packed in glassine bags, which transmit light (Fan et al., 1983). Peroxide values in the glassine-packed chips were also consistently higher. Matz (1984) noted that some opaque packaging films are opaque to visible light but allow ultraviolet radiation to pass through. Foil-

laminated bags offer greater protection from light, and their use in snack food packaging has increased during recent years.

Snack Foods and Oil Quality

Chip makers aim to minimize rancidity in chips up to 90 days old, but chips are generally sold or removed from store shelves by 50 days. Oils used in commercial chipping are not abused as much as oils in fast food operations. Thompson et al. (1967) compared cottonseed oils used by a potato chip company and another food manufacturer. The chip oil was not abused; the damage in the other used oil was visible. Still, deterioration in the frying oil is reflected in the final chip. The longer a frying oil is used, the greater is the decrease in the quality of the oil and the chips. After the hydrogenated oil was heated for 27 hours, chips cooked in that oil developed rancidity in four days at 145° F. Potato chips fried in fresh oil turned rancid after 96 days at that temperature (Carlin and Lannerud, 1941).

Fresh and heated oils used by commercial potato chip manufacturers were examined (Table 5-8). Cottonseed oil was the predominant oil observed in use in a study by Melnick et al. (1958). For 95% of the chippers, the increase in free fatty acid value was 0.60% or less and the iodine value decreased by 3.0% or less in the heated frying oils. Corn oil exhibited the greatest increase in free fatty acid values after heating, 0.39%, while FFA in cottonseed cooking oil increased by only 0.17%.

Antioxidants protect the chips against oxidation during

storage and several synthetic antioxidants are approved by the FDA for use in foods. Cort (1974) fried potato chips in cottonseed oil that contained five different antioxidants. The chips were stored in open containers at 45° C and the number of days to develop 70 Meq of peroxide were calculated. Propyl gallate was found to be the most effective (Table 5-9). Antioxidants also reduce the amounts of volatiles produced by heated oils (Min and Schweizer, 1983). Evans and co-workers (1971) reported, however, that room odor was not affected by antioxidants in the frying oil.

Tocopherols are natural antioxidants with vitamin E activity that may be used in chips marketed as "natural" or "healthy". Du Plessis et al. (1981) extracted oil from potato chips cooked in peanut or cottonseed oil at three periods during storage. The amounts of alpha and gamma tocopherol in chips fried in cottonseed oil were 47.0 and 38.5 mg/100g oil respectively at 27 weeks. The chips cooked in cottonseed oil contained more of the tocopherols at each sampling period up to 27 weeks of storage and showed less of a drop from original values than did the extracted peanut oil.

Texture

The texture of finished snack chips is dependent upon the amount and type of fat absorbed and chip makers want to minimize fat absorption. According to Matz (1984), fat pickup is reduced by 10-15% when the chip is fried in a vegetable oil, such as cottonseed oil, rather than fats which are solid at room temperature due to better draining of oil.

In addition to the amount of fat absorbed, the quality of the fat will affect texture. If the solid fat index (SFI) of the absorbed fat is too low the product will exhibit a shiny, oily appearance and the surface texture may be weakened. If the SFI is too high, the chip texture may be gummy or waxy (Vandaveer, 1985; Matz, 1984). Bessler and Orthoefer (1983) noted that the non-oily appearance of chips fried in cottonseed oil is due to the greater proportion of diunsaturated and monosaturated triglycerides in this oil. Weiss (1970) has indicated that the use of cottonseed oil in chip frying results in a pleasant mouthfeel and a bright finish.

Salad and Cooking Oil Applications

Most consumers are unaware of the distinctions between salad and cooking oils. Salad oils may be used for cooking but are winterized or are otherwise low in saturated fatty acids to prevent clouding during refrigeration. Cooking oils are used for pan frying, deep fat frying, and in packaged baking mixes and are not winterized. Many types of vegetable oils can be used but, in the United States, soybean oil dominates (Figure 5-5). While the quantity of cottonseed oil used for cooking and salad purposes is much smaller than the amount of soybean used, many of its characteristics, particularly oxidative stability, are superior (Table 5-10).

Stability

The shelf stability of an oil is a major concern of both consumers and manufacturers. Once opened, oils and oil-

Table 5-8. Changes from fresh oil to heated oil in free fatty acid and iodine values of fats used in the commercial manufacture of potato chips (From Melnick et al. 1958)

Type of Fat	No. of Chippers	Change in FFA (%)	Change in IV (%)
Corn Oil	9	+0.39	-1.01
Cottonseed Cooking Oil	9	+0.17	-1.48
Winterized Cottonseed Oil	18	+0.19	-0.71
Lightly Hydrogenated Cottonseed Oil	10	+0.24	—
Shortening	27	+0.18	-0.75
Oil/Shortening Blend	16	+0.24	—

Table 5-9. Stability of potato chips fried in cottonseed oil with various antioxidants and stored at 45°C (From Cort, 1974)

Antioxidant ^a (200 ppm)	Days to reach rancidity
Control (None)	10
BHA	10
AP	15
BHT	14
PG	24
Dilauryl Thiodipropionate	14

^aBHA = butylated hydroxyanisole, AP = Ascorbyl palmitate, BHT = butylated hydroxytoluene, PG = propyl gallate.

containing products may remain on household shelves at room temperatures for months. Exposure to oxygen, light, and metals contribute to the rate of autooxidation in oils. Since foods fried at home are usually consumed shortly after preparation, and the oil is often discarded after use, deterioration due to thermal factors is not as important to consumers as it is for commercial operations. Under accelerated storage conditions of 60° C for 16 days, peroxide values in samples of corn, olive, peanut, safflower, sunflower, and soybean oils were higher than for cottonseed oil, indicating that the cottonseed oil was more resistant to oxidation (Snyder et al., 1985).

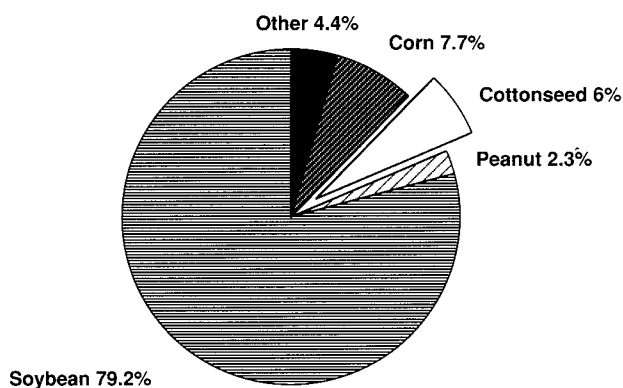


FIGURE 5-5. 1987-1988 SALAD AND COOKING OIL USE IN THE UNITED STATES (From: USDA, 1989a)

Table 5-10. Characteristics of commercial salad and cooking oils (From Krishnamurthy, 1982)

	Salad Oil			Cooking Oil		
	Winterized Cottonseed	Olive	Corn	Soybean	Cottonseed	Peanut
Iodine Number	112	85	125	130	108	95
Free Fatty Acids	0.02	1.5	0.05	0.02	0.03	0.03
AOM ^a	10	20	10	8	10	12
Cold Test (hrs.)	20	>24	No Cloud	No Cloud	<1	<1

^aNumber of hours to reach a peroxide value of 125.

In another accelerated storage study, at 65° C, Durance (1986) found that blending cottonseed oil with canola oil reduced the formation of oxidation products and improved the sensory qualities. After 12 days, peroxide levels in the blends containing 50-100% canola were nearly double those of the oils with 75-100% cottonseed oil. The acceptability of the odor of blends higher in cottonseed oil were also better.

Antioxidants in Salad and Cooking Oils

Oil stability may be preserved by the addition of antioxidants after processing. Sherwin and Luckadoo (1969) added several types of antioxidants to crude vegetable oils and concluded that crude cottonseed oil is resistant to peroxide formation under accelerated storage conditions. TBHQ added to deodorized cottonseed oil appeared to prevent oxidation better than the other antioxidant compounds studied, particularly when TBHQ was also added to the crude oil, which was stored for 12 months prior to deodorization.

Warner and co-workers (1978) stored cottonseed, soybean, and peanut oils with and without citric acid or antioxidants at 60° C for up to eight days at which time sensory flavor acceptability of the oils were evaluated. The addition of 0.01% citric acid to cottonseed oil resulted in higher flavor scores after eight days than the cottonseed oil with no additive or 0.076% Tenox 6, which is a mixture of BHA, BHT, citric acid and propyl gallate (Figure 5-6). The highest score was given to the cottonseed oil with both citric acid and Tenox 6 added. While the peanut oil samples with similar treatments received slightly higher sensory ratings than did the cottonseed oil, the soybean oil scores were lowest after storage.

Packaging of Shelf Oils

The type of packaging used for salad and cooking oils is very important. Bottles of oil may sit on the shelves of grocers or consumers for many months and be exposed to fluctuating conditions. Packaging materials should be resistant to permeation by oxygen and moisture, and preferably not transmit light, especially the ultraviolet wavelengths which can catalyze the formation of free radicals. Leo (1983) compared the relative stability of like oils when packaged in different mate-

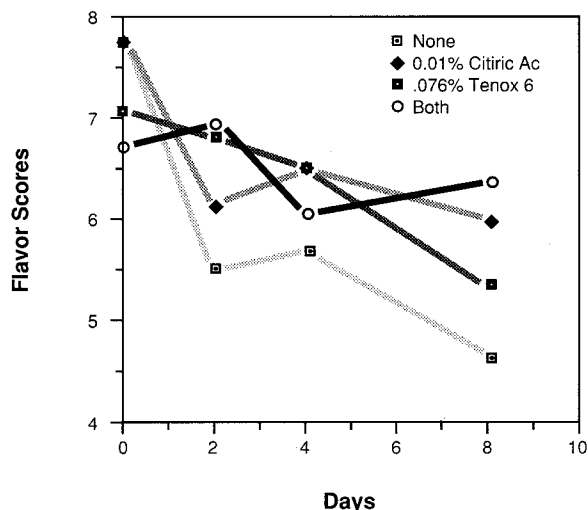


FIGURE 5-6. EFFECT OF ADDITIVES ON THE FLAVOR SCORE OF STORED COTTONSEED OIL (From Warner et al, 1978)

rials and found that metal will preserve oil stability for over 24 months while at the other end of the scale, high density polyethylene holds oils stable for only 3-6 months. Amber glass, flint glass, and polyvinyl chloride showed stability periods of 18, 12-26, and 9-12 months respectively.

Metal cans are the most expensive form of packaging, but do not transmit oxygen, water, or light. On the negative side, in addition to their heavier weight compared to other types of packaging, metal ions may contaminate the oil, thereby promoting oxidation. The many types of plastics available do allow passage of varying amounts of oxygen and water vapor, and about 90% of visible light (Leo, 1983). Despite these disadvantages, such materials are more popular with consumers for their light weight and resistance to breaking.

Another study by Evans et al. (1974) revealed that bottled cottonseed oil packaged with a nitrogen headspace maintained its flavor quality better than did cottonseed oil bottled or canned with air. The stored cottonseed oils had flavor scores about one unit higher than the scores for soybean oils at the end of one year. The nitrogen-protected cottonseed oil had a peroxide value of zero throughout the year-long experiment. The highest peroxide values found for cottonseed oil were those of oil in metal cans.

Effects of Storage on Cottonseed Oil Quality

Cottonseed oil seems to hold up well under varying storage conditions. Figure 5-7 gives a presentation of changes in flavor scores for several cottonseed salad oil samples as presented by Bauman and Whitten (1970). The oil samples were held for up to two years at six different temperatures ranging from 55° F to 110° F. Every three months, samples of the oils were compared by a taste panel to the same oil held at 0° F for the same time period. Figure 5-7 shows the variations from the cold-stored oil that were noted for the cottonseed oils stored at the six different temperatures involved in the test. Although the oils seemed to decrease slightly in quality with time, there was no clear-cut indication that warmer storage temperatures were more detrimental to quality. The differences in flavor scores were slight, and the variation in individual scores by the panel members were great enough that the apparent decreases with time were assumed not to be important. The researchers concluded that the quality of the cottonseed salad oils in the test had not been seriously affected by either time or temperature of storage during the two year period. It may be that the level of antioxidants naturally present in cottonseed oil was partially accountable for this observation.

Mayonnaise

Mayonnaise is defined by the Food and Drug Administration to be a semisolid food prepared with at least 65% vegetable oil, plus egg yolks or whole eggs, vinegar, lemon or lime juice, and seasonings (Krishnamurthy, 1982). Since mayonnaise usually contains at least 80% oil, the quality of the oil used is important to the flavor and stability of the emulsion.

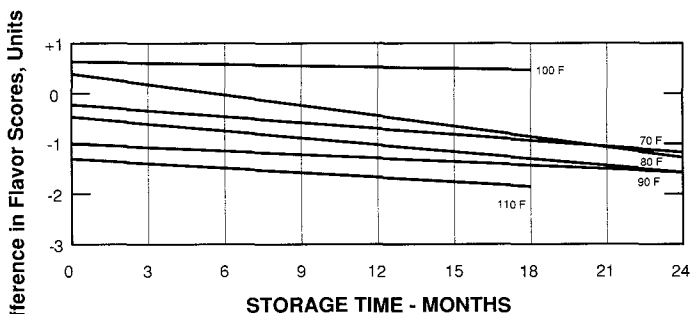


FIGURE 5-7. COTTONSEED SALAD OIL; AVERAGE DIFFERENCE IN FLAVOR SCORES BETWEEN OILS STORED AT SIX TEMPERATURES AND OIL STORED AT 0° F. (From Bauman and Whitten, 1970.)

If an oil is used that has not been winterized, the formation of crystals during refrigeration will break the emulsion, causing the oil fraction to separate from the other ingredients. Although soybean oil is often used in the manufacture of mayonnaise, winterized cottonseed oil is also an excellent oil and for many years was the standard oil for this product. Cottonseed oil must be winterized or the mayonnaise will separate and cloud.

Salad Dressings

Many types of salad dressings are made commercially and at home. The role of an oil in a salad dressing is to provide a pleasant mouthfeel and to allow the tastes of the spices and vinegar to be perceived. The cloudiness that develops when non-winterized oils are refrigerated is not attractive, and prevents easy pouring. Peanut oil cannot be used in salad dressings because it cannot be winterized. Winterized cottonseed oil is used in commercial and home-made dressings. Oils with high linolenic acid contents can be used in salad dressings since oxidation is less likely to develop during cold storage. However, commercial dressings are often packaged in clear glass and are not refrigerated prior to opening, so some rancidity could develop before use.

Cooking Oils

Stronger flavors are more acceptable in cooking oils than in salad oils. Olive, peanut, and sesame oils are favored in certain ethnic cuisines for the characteristic tastes which they impart to foods. While cottonseed oil has a light, nutty flavor which enhances, rather than adds, to the flavor of the food being cooked, it is sufficiently bland for use in foods where a stronger oil could not be used.

Cocoa Butter Substitutes

Cocoa butter, the fat derived from cocoa beans, is a unique material used in confectionary manufacturing. The unstable market conditions for cocoa cause fluctuations in the price and availability (Babayan, 1978) and researchers have investigated the use of domestically grown oils, including cottonseed oil, as cocoa butter substitutes.

While the cocoa butter contributes to the attractive gloss of chocolate, at warm temperatures, the crystalline structure may change, and a grayish coating, or fat bloom, develops on the surface of the chocolate.

Lauric fats, such as palm kernel and coconut oil, possess some of the qualities of cocoa butter but may develop soapy off-flavors. Cottonseed, soybean, and other nonlauric vegetable oils must be hydrogenated and/or fractionated before they can be blended with or substituted for cocoa butter. The major drawbacks of these oils are poor melting and textural characteristics.

The stearine fraction removed from cottonseed oil during winterization has an iodine value of about 72. Selective hydrogenation of this stearine to an IV of 28-42 and fractional crystallization produces a fat with approximately two-thirds of its triglycerides as 1,3 disaturated molecules (Feuge, et al., 1973). The fats with higher melting points could be processed to a hardness equivalent to that of cocoa butter (Lovegren, et al., 1973). Experimental confectionary coatings made with these fractions and cocoa powder had good texture and gloss and did not develop fat bloom after several months of storage. One problem encountered with the mixing of other fats with cocoa butter is the depression of the maximum softening point. However, when these cottonseed oil fractions were blended with cocoa butter, the softening point was only lowered by 0.1-0.2° C.

Several other processes have been developed for converting cottonseed oil to a cocoa butter substitute. Frankel and co-workers (1970) employed a chromium catalyst in the hydrogenation of cottonseed oil stearine. The characteristics of the substitute are compared with those of cocoa butter in Table 5-11. Cottonseed oil stearine appears to be an adequate replacement for cocoa butter in many respects and its use in confections is likely to increase.

Table 5-11. Comparison of simulated cocoa butter made from hydrogenated cottonseed oil stearine with cocoa butter (From Frankel, 1970)

	Hydrogenated Stearine Fraction of Cottonseed Oil	Cocoa Butter
Palmitate (%)	58.0	24.4
Stearate (%)	1.0	35.4
Monoene (%)	37.6	38.1
Diene (%)	3.4	2.1
Trans acids (%)	7.2	—
Iodine value	38.0	36.7
Melting range (°C)	30-40	34-35

Margarine

Margarine was invented by the French chemist Mege Mouriés in 1869. Since its introduction, margarine has made great strides to change its image from a butter substitute to that of an acceptable, respected product in the fats and oils industry. Today there are numerous margarine products in

the marketplace aimed at satisfying various market segments. Massiello (1978) identified ten varieties of margarine products which included regular stick, whipped polyunsaturated, liquid, diet spreads and vegetable oil spreads. Improved technology is greatly responsible for the diversification of margarine and in helping it become established as a high quality dietary product.

U.S. Federal Standard of Identity

Margarine is a water-in-oil emulsion which is defined by statute and must meet certain criteria in order to be labelled "margarine". The standard of identity requires that it must contain at least 80% fat or oil and that the aqueous phase (16-20%) may include water, nonfat solids and/or whey. Optional ingredients which may be added are salt, emulsifiers, color additives and nutritive carbohydrate in the form of sweetener. It is also specified that margarine must contain 15,000 I.U. of vitamin A. The addition of vitamin D, usually at a level of 2000 I.U., is optional.

Although not defined by statute, the term "spread" applies to margarine-like products containing less than 80% fat. It is specified that the product name should include the term "spread", the total percentage of fat, and a listing of each fat ingredient in the order of predominance (Chrysam, 1985).

The last category of products are "diet" and "reduced calorie" margarines. These categories of margarine may not exceed 40% and 53% fat respectively in the formulation and the latter must show a caloric reduction of at least 33%. These types of margarines have gained rapid consumer acceptance and with current health concerns may be expected to increase in marketshare. In 1981 the average American consumed 11.2 pounds of margarine and only 4.4 pounds of butter (Lecos, 1983). Data for 1965-1985 shows that butter consumption decreased 9% while margarine increased 23% (Hoskin and Putnam, 1987).

Source Oils

Throughout the history of development of margarine a variety of fat and oil sources have been used for the formulations. Between 1922-1932 coconut oil was used extensively, but as the expense increased a trend toward use of domestic oils occurred. By the late 1930's a dramatic shift in favor of cottonseed oil had occurred. By 1945 both cottonseed oil and soybean oil were almost equally dominant (215 million lbs. cottonseed oil, and 211 million lbs. soybean oil (Black, 1948).

Today the bottom line for the selection of source oils is based on price and availability and soybean oil dominates this marketplace. Figures for 1986-87 indicate that soybean oil accounts for 1,660 million pounds followed by corn oil at 248 million pounds while 36 million pounds of cottonseed oil were used (Table 5-12) (Chrysam, 1985).

Margarine Formulation

When developing margarine formulations, consideration is given to technical attributes such as spreadability, mouth-

Table 5-12. Oils used in U.S. margarine manufacturing (From Chrysam, 1985 and The National Association of Margarine Manufacturers)

Oil	Millions of pounds								
	1950	1955	1960	1965	1970	1975	1980	1983	1986/87 ^a
Soybean	312	746	1105	1112	1410	1568	1651	1549	1660
Cottonseed	418	278	136	114	68	46	25	34	36
Corn	1	0	55	161	185	188	222	212	248
Peanut	7	2	4	4	0	1	—	—	—
Coconut	0	6	4	5	10	20	—	—	—
Safflower	—	—	—	10	22	7	—	—	—
Other vegetable	13	17	1	14	1	39	34	15	—
Lard	4	13	56	100	90	45	104	41	22
Beef fats	9	9	6	14	8	7	^b	—	—
TOTAL	764	1071	1367	1535	1794	1921	2036	1850	1973

^aUSDA Oil Crops: Situation and Outlook Report OCS-17, April 1988

^bIncluded under lard.

Table 5-13. Typical solid fat index values for U.S. margarines (From Wiedermann, 1978)

Product	50°F	70°F	80°F	92°F	100°F
Stick (3 Components)	28	16	12	2-3	0
80% liquid oil print	15	11	9	5	2
Soft tub products	13	8	6	2	0
Liquid oil + 5% of hardfat	7	6	6	5.4	4.8
Bakers	27	18	16	12	8
Roll-in	29	24	22	16	12
Puff Paste, Veg/A-V.	26	24/21	23/20	22/16	21/15

feel and nutritional composition. While price and availability are major factors, it is also necessary to consider the solid fat index (SFI), flavor stability and crystallization properties.

The SFI depends on the triglyceride composition of the fat and influences the physical properties of consistency and plasticity which affect margarine spreadability. Typical SFI values for different types of margarines at various temperatures are given in Table 5-13. Relevant flavor stability aspects of cottonseed oil are discussed elsewhere in this chapter.

The third factor affecting the quality and functional properties of margarine is the crystallization properties of the component fats. Fats and oils exhibit different crystalline behavior and structure when cooled. The cooling produces various types of crystals which form a crystalline lattice or network. The beta prime crystal characteristic of cottonseed oil can form a network that uniformly entraps oil and the aqueous phase. This results in finished products with a consistent texture and a smooth, creamy appearance. However, a beta crystal network lacks this ability due to the large size and shapes of the fat crystal. This may result in a grainy product and even possibly an "oil-off" tendency.

Cottonseed oil is noted for its ability to form the beta prime crystal due to its palmitic acid content over 20% and positional distribution at the 1 and 3 carbons. This property helps promote the development of the proper crystalline network in plastic margarines. The blending of one to four oil

stock bases may be used in margarine production and hydrogenated cottonseed oil is often used as a hardfat at a 5% level or more. The amount of cottonseed hardfat, along with the degree of hardness, which is directly related to the degree of hydrogenation, will determine the ability of the fat to exhibit beta prime properties (Wiedermann, 1978). This can also be achieved without using hard fats by using a beta prime fat at levels of 20% or greater provided it has the highest melting point of all component fats. Partially hydrogenated cottonseed oil is often used in order to impart the beta prime properties in margarines, especially those used for cakes and icings.

Due to these desired functional properties and other attributes, cottonseed oil has been used as a source oil for many margarine products. In a 1977 margarine survey, the fatty acid composition of the various margarine formulations was analyzed and compared. Weihrauch (1977) reported cottonseed oil as a source oil in 19 of 40 margarines from local supermarkets and that stick margarines made from partially hydrogenated soybean oil and cottonseed oil were by far the largest category represented.

Shortening

When used in baked goods, shortenings reduce the amount of binding between gluten proteins and carbohydrates resulting in strands that are shorter, causing the texture to be softer and more tender. Historically, the term referred to lard fat used to tenderize or shorten baked foods, especially pie crusts and breads. There are several ways to classify shortenings including: (1) fat source, (2) functional use, (3) physical state, (4) amount of fat, and (5) package form. Usually the source of fat is considered to be either animal or vegetable, but may include specific fats that are used in the formulation.

The physical state refers to the solid, liquid or semisolid condition of the fat. If high fat products contain various non-fat materials, they are referred to as margarines or other special products, but an all-fat material is considered to be a shortening. Categorizing shortenings according to their functional or end usage takes into consideration whether they are produced for use in baked goods, icings, fillings or to fry foods. There are many fat products that serve a variety of functions in food systems.

Product Development

Shortening products are prepared with various blends of many different oils under diverse processing conditions. The processing conditions, ratio of solids to liquids, nitrogen amounts, crystalline properties, and other factors must be considered in order to achieve the desired functionality and nutritional qualities.

Different base stocks are used in order to extend the plastic range and stability and to provide proper crystallization patterns. Usually a partially hydrogenated base stock is blended with a fully hydrogenated oil, especially cottonseed oil. Cot-

tonseed oil "flakes" with an IV of 2-5 are used for this purpose. The objective is to achieve a shortening with a solid fat index (SFI) that will produce the desired plasticity. These values of SFI (depending on the application) are usually between 15 and 22 in the 55-87° F range. Above an SFI of 22, shortenings may become too brittle, below 15 they become too fluid (Latondress, 1980).

Table 5-14 indicates the upper SFI values of three base stocks and two shortenings. By blending these base stocks with the appropriate additives, many shortenings with a wide range of properties can be produced. Some of the additives that may be used include, plasticizers, emulsifiers, antioxidants, metal scavengers, antifoaming agents, flavors and nitrogen. Nitrogen at a level of 10-15% by volume results in a bright, white opaque appearance (Chyrsam, 1985).

Table 5-14. Solid fat index of base stocks and shortenings (From Chyrsam, 1985)

Base stock or shortening	SFI			
	50°F	70°F	92°F	104°F
Base stock #1	18	8.8	—	—
Shortening #1 ^a	24	20	15	12
Base Stock #1A	21	13	3.4	—
Shortening #2 ^b	27	20	14	7.9
Base stock #2	43	29	11	1.7

^aBase stock #1 (88-89%) plus 11-12% hardfat.

^bBase stock #1A (92-93%) plus 7-8% hardfat.

Fat Crystallization

The crystalline structure of fat is important in formulation of shortening, margarine, and products which require these ingredients such as baked goods, confectionery icings, fillings, and whipped toppings. Each crystal form has its own physical property for plasticity, hardness, softness, texture, solubility, mouthfeel, aeration, and others depending upon the food into which the fat is incorporated. Crystalline behavior involves polymorphism, the property of a triglyceride to exhibit multiple crystal forms upon melting without a change in chemical structure. Factors such as purity, temperature, rate of cooling, presence of crystalline nuclei and type of solvent all affect polymorphic behavior (Nawar, 1985). Fatty acid composition and positional distribution of the triglyceride molecules are also important.

Triglycerides typically exhibit three major crystalline forms: alpha, beta prime, and beta. Characteristics of each form are shown in Table 5-15. The alpha crystal, which forms just below its melting point, is least dense, highly unstable and readily transforms to a more stable beta prime crystal. It requires low temperatures for stability. The beta prime has a melting point which generally falls somewhere between that of alpha and beta crystals. However, there have been some cases in which beta prime crystals have had higher melting points than beta. Some glycerides of cottonseed hardstock crystallize in a beta prime form of high density which results

in greater stiffening power (Nawar, 1985). The beta prime crystal forms as tiny, delicate needles approximately one micron in length and seldom grow.

The beta crystal is the most stable form. Usually it is quite large and coarse. It is approximately 25-50 microns in length and may grow to more than 100 microns (Hoerr, 1960). The development and growth of beta crystals in margarine and shortening will result in a product which is grainy in texture and appearance.

Table 5-15. Characteristics of the polymorphic forms of monoacid triacylglycerols (From Nawar, 1985)

Characteristic	Alpha Form	Beta Prime Form	Beta Form
Chain packing	Hexagonal	Orthorhombic	Triclinic
Short spacing (angstroms)	4.2	3.8 and 4.2	4.6
Characteristic infrared spectrum	Single band at 720/cm	Double at 727 and 719/cm	Single band at 717/cm
Density	Least dense	Intermediate	Most dense
Melting point	Lowest	Medium	Highest

Beta Prime Factors

The affinity of a fat or oil to form beta prime crystals is dependent on several factors: (1) the amount of palmitic acid in the fat, (2) the distribution and position of both palmitic and stearic acids on the triglyceride molecule, (3) the degree of hydrogenation or hardness of a fat, (beta prime crystallization increases with the degree of hydrogenation), and (4) the degree of randomization of a fat (Wiedermann, 1978). Beta prime crystals are typical of randomized fats. The importance of position and distribution of palmitic acid is seen when comparing cottonseed oil to lard. Even though each of these fats contain about 23% palmitate, (cottonseed oil is 23.5% palmitate, the highest of the domestically produced vegetable oils) beta prime is characteristic of cottonseed oil while beta is characteristic of lard (Table 5-16). This is due to the fact that palmitate predominates at the 1 and 3 position in cottonseed oil triglycerides and predominates in the 2 position in lard.

Table 5-16. Classification of fats and oils according to crystal habit (From Wiedermann, 1978)

BETA	BETA PRIME
Soybean	Cottonseed
Safflower	Palm
Sunflower	Tallow
Sesame	Herring
Peanut	Menhanden
Corn	Whale
Canbra	Rapeseed
Olive	Modified Lard
Coconut	Milk Fat (butter oil)
Palm Kernel	
Lard	
Cocoa Butter	

The beta prime crystalline structure results in desirable shortening properties including good aeration, smooth appearance and excellent creaming properties. The beta form may result in plastic shortenings that have a grainy or waxy texture that may cause a loss of various functional properties, especially creaming ability. As a result, some vegetable oils require blending with beta prime hardfats at a minimum level of 5%, or with 20% of an oil that forms beta prime crystals. In addition, this fat must have a higher melting point than the other component oils in order for the entire fat to crystallize in the stable beta prime form. Thus, vegetable oils which produce beta crystals such as sunflower, safflower, and canola require blending with a beta prime crystal forming oil or hardfat in the preparation of plastic shortening (Chrysam, 1985). One way to achieve this is by blending these oils with fully hydrogenated cottonseed stearines (Bessler and Orthofer, 1983).

Balance of Source Oil Properties

In order to balance the functional and nutritional qualities of a shortening, it is necessary to consider both the inherent properties of the source oils and properties determined by processing. Consideration of the characteristics of source oils, results in finished products with the desired traits.

One of the recent objectives has been to obtain a particular fatty acid profile along with the needed functional properties. Often the nutritional objective is to lower the saturated level and to increase monounsaturated and polyunsaturated fatty acids.

Using Hydrogenated Cottonseed Oil in Frozen Desserts

Cottonseed oil can be used to replace butterfat in the manufacture of frozen desserts (Farmer, 1989). It is important to choose a fat that has been tailored by proper hydrogenation to produce rapid overrun, resistance to both churn out and development of sandiness, and yield desserts having smooth melt-down with no solids separation or emulsion break-down. Because of its superior flavor, crystalline behavior

characteristics, and ease of hydrogenation, cottonseed oil is an excellent choice for frozen desserts.

Frozen desserts fall into two types, (1) soft-serve and (2) hardened. For best results fats tailored to different specifications should be used in each case. The fat used primarily for soft-serve can, however, be used with satisfactory results for the hardened products but, fats tailored for the hardened products should not be used for soft-serve. The softer (lower solid fat index) fat is very resistant to churn out experienced with soft-serve freezers and gives high rapid overrun in batch freezers. Examples of typical analytical characters for the two types of fats are shown in Table 5-17.

The mixing and manufacture of frozen desserts with hydrogenated cottonseed oil is handled in much the same way as desserts made with butterfat or other vegetable oils with regard to pasteurization, homogenizing, cooling, etc. Non-fat skim, condensed skim, or non-fat dry milk solids, can be used as source of serum solids and hydrogenated cottonseed oil can be substituted for the butterfat.

Non-fat dry milk solids should be reconstituted properly. Normally the milk product is put into the mix tank along with sugar and corn syrup solids. The fat can be melted separately then added, or the solid fat can be added to the mix and allowed to melt as the mixture comes to pasteurization temperature. Pasteurization temperatures and homogenization pressures are the same as those used for butterfat based desserts.

Typical formulas illustrated in Table 5-18 show use of a stabilizer. Hydrogenated cottonseed oil based frozen desserts do not require the addition of an emulsifier but better results are usually obtained if one is used. The mono-diglyceride type emulsifiers are recommended. These emulsifiers help in getting a high rapid overrun and a drier product from the freezer. Chemical type emulsifiers tend to decrease the overrun and contribute to a more rapid churn out of fat in the soft-serve products.

Table 5-17. Typical analytical values for hydrogenated cottonseed oils used in either soft-serve or hardened frozen desserts. (From Farmer, 1989)

Value	Type A hydro-cottonseed oil for soft serve/batch type freezers	Type B hydro-cottonseed oil for hardened type continuous freezers
Iodine Value	69.0	71.8
Wiley melting point	41.2	36.3
Solid Fat Index		
@ 10.0°C	56.0	38.0
@ 21.1	40.0	21.5
@ 26.7	32.0	14.5
@ 33.3	19.5	3.5
@ 40.0	0	0

Table 5-18. Typical formulas for soft-serve or hardened frozen desserts using hydrogenated cottonseed oil. (From Farmer, 1989)

Ingredients	Formulas: Kg/1000 Kg	
	6% Fat Soft-Serve Dessert	10% Fat Hardened Dessert
Hydro-Cottonseed Oil		
Type B	60	—
Type A	—	100.00
Non-fat dry milk solids	140	120.0
Water	655	615.8
Sugar	140	120.0
Corn Syrup Solids	—	40.0
Stabilizer	3	3.0
Emulsifier	2	1.2
Flavor	optional	optional
Vitamins	optional	optional

Corn syrup solids are usually preferred over corn sugar because they do not depress the freezing point of the mix as much as corn sugar. Both products are used to increase the total solids without making the product too sweet. In general, not more than one third of the total sugar solids should be corn syrup solids or corn sugar.

The fat content of hardened frozen desserts can be varied from 4% to over 16%. These products should contain a minimum of 10% fat. Generally the higher fat content products are judged "better" or of higher quality than those with lower fat contents. Likewise overrun affects the eating quality of the

frozen dessert, with lower overrun being judged superior to the high overrun products. Soft-serve products run lower in fat and should have a higher overrun than the hardened products.

As with any food product, the eating characteristics and quality are dependent on the ingredients used as well as the manufacturing techniques. Cottonseed oil is known for its "buttery flavor" and ability to prevent sandiness due to the beta prime crystal promoting properties and is preferred because of the unique flavor/texture properties.