REVIEW

Review of Stability Measurements for Frying Oils and Fried Food Flavor[1]

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Measurements of degradation in frying oils based on oil physical properties and volatile and nonvolatile decomposition products were reviewed. Rapid methods by means of test kits were also considered. Factors that affect the analysis of total polar components (TPC) in frying oils were examined. Relationships between TPC, free fatty acid (FFA) content, Food Oil Sensor readings (FOS), color change (ΔE), oil fry life and fried-food flavor were evaluated. Flavor scores for codfish, fried in fresh and discarded commercial frying oil blends, were dependent upon individuals in the consumer panel (n = 77). Part (n = 29) of the panel preferred the flavor of fresh fat; others (n = 24) didn't; the rest (n = 24) had no preference. FFA, FOS and TPC were analyzed in two soybean oils and in palm olein during a four-day period in which french fries were fried. Flavor score and volatiles of potatoes fried on days 1 and 4 in each oil were also determined. TPC, FFA and FOS significantly increased ($P < 0.05$) in all oils during the frying period. TPC and FFA were highest in the used palm olein, and flavor of potatoes fried in palm olein on day 1 was less desirable than those fried in the soybean oils. Potatoes fried in day-1 oils had significantly higher concentrations ($P < 0.10$) of several pyrazines and aldehydes than those fried in day-4 oils.

KEY WORDS: Degradation, flavor, fried-food flavor, frying oil assessment, quality, volatiles.

During frying, oils degrade mainly *via* thermal oxidation and form volatile (VDP) and nonvolatile decomposition products (NVDP). While VDP are responsible for deep-fried flavor, measurement of NVDP provides better methods for following degradation of a frying fat. Although measurement of total polar components (TPC) is a popular method for following frying oil degradation, more research is needed to determine the TPC levels at which different frying oils should be discarded and to relate TPC levels to fried food quality for different types of frying oils. Other methods, such as measurement of free fatty acid (FFA) level, changes in oil color and polymer concentration and various quick tests, also have been used successfully for following degradation of frying oils. The method most often used by different countries to determine when to discard a frying oil, however, is still sensory evaluation. The flavor likability of fried food is dependent upon consumer perception and is affected by type of oil used and the length of time the oil has been heated or used for frying. Consumer gender also may affect the flavor likability of one oil compared with another. Also, more research is needed to clarify the relationship between fried-flavor likability and concentrations of specific compounds produced *via* thermal oxidation of frying oils. The objective of this paper is to review measurements of degradation in frying oils and factors that affect fried-food flavor.

Physical and chemical changes in oil during frying. The frying process is summarized in Figure 1 (1). Food placed in hot fat is heated quickly to the point where water is vaporized, and the resulting steam causes a boiling action in the oil. This boiling action increases aeration in the oil, which results in increased oxidation of the oil with formation of hydroperoxides, the primary oxidation product. These peroxides are extremely unstable and decompose *via* fission, dehydration and formation of free radicals to form a variety of chemical products, both VDP and NVDP. The volatile products are constantly being removed by volatilization, aided by the evolving steam, as well as being formed by continuing oxidation, hydrolysis and thermal or pyrolytic reactions. The NVDP are formed mainly from the oxidation reactions but may also be formed *via* the thermal or pyrolytic pathway. NVDP are removed from the frying oil *via* absorption by the food being fried, by deposition on fry kettle parts, and possibly by filtration. The NVDP consists mainly of polymers, dimers and trimers (1). In general, those reaction products with molecular weights greater than 1800 daltons are NVDP, and those with molecular weights less than 1800 daltons are VDP (2). However, the triglycerides, which comprise >99% of an unused frying oil, have molecular weights in the range of 900–1000 daltons and are not very volatile at normal frying temperatures (<200°C)(3). Besides the degradative processes in the oil, solubilization of components from food being fried, including colored compounds and food lipids, also contributes to the heterogeneity of the components found in used frying fats/oils and thus to increased rates of degradation (Fig. 1).

The chemical changes in the frying fats also result in changes in the physical characteristics. The color of a fat/oil darkens, and with increasing content of polymers, viscosity

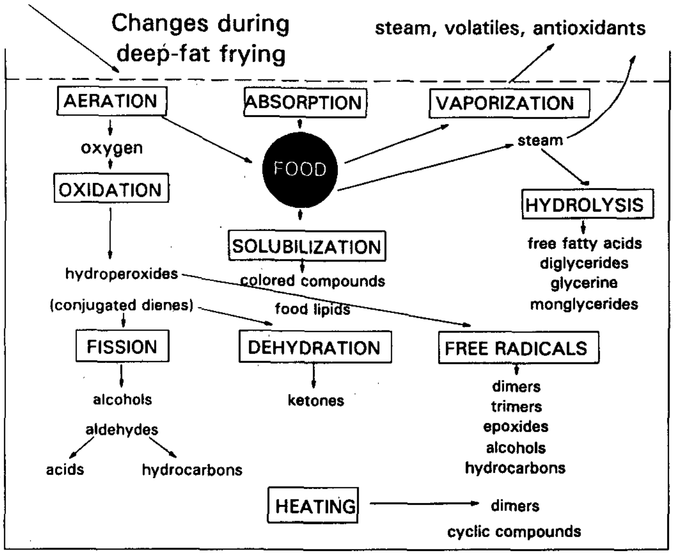

FIG. 1. Deep-fat frying process (Ref. 1).

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increases, and greater foaming of the oil occurs. Some of the more volatile components, such as FFA, accumulate to the point where the smoke point is decreased. The aroma and the flavor of the oil also change with increased frying time, as do the color and flavor of the food fried in the oil.

A number of factors affect the stability of the oil during frying, including the frying temperature, time of heating, frequency of frying food, exposure to oxygen, presence/absence of antioxidants, exposure to prooxidants and replenishment of oil during frying. But with all these factors being equal, the stability of the frying oil is decreased with increased degree of unsaturation in the constituent fatty acids.

Methods for measurement of frying oil degradation. Although methods for the measurement of progressive deterioration in frying oils exist that determine unstable VDP, the best methods measure stable NVDP. Most of these methods require laboratory techniques for measurement rather than quick test kits. Several methods determine changes in physical characteristics of the frying oil, such as viscosity, foam height, smoke point and color (Table 1). Measurements of conjugated dienoic acids, FFA, peroxide value, carbonyl content, acid value and volatiles by gas–liquid chromatography (GLC) (Table 1) are dependent on formation of unstable products and/or VDP. The other techniques listed in Table 1 are based largely on accumulation of NVDP.

Quick test kits are also available to measure deterioration of a frying oil by means of either VDP or NVDP (Table 2). The Fritest, Spot test and the Shortening Monitor Strip measure concentrations of VDP, whereas the Food Oil Sensor (FOS), Rau-Test, ACM test and TPM Colorimetric test detect NVDP. Sources of kits for these quick tests may be found in a 1991 review by White (34) on methods for measuring changes in frying oils.

One method not listed in Tables 1 and 2 is sensory evaluation. In the fast-food outlets, restaurants and other places that produce fried products, the color, flavor and acceptability of the fried food or the frying oil are the most often-used tests for determining both degradation of a frying oil and the time to discard or replenish oil. This sensory evaluation usually is done by a single judge and is dependent not only upon that person's perception and acuity but also on the practices of that food outlet or processing unit.

TPC. The ultimate instrumental or chemical method for determining when a frying oil should be discarded has not yet been devised. However, during the past few years, the measurement of TPC in frying oil has been proposed as a possible method, and many workers believe it is one of the best indicators of frying oil quality. TPC increase in quantity during frying oil degradation and are defined as the sum total of the materials that are not triglycerides (35). Therefore, TPC in the unused frying oil includes sterols, tocopherols, mono- and diglycerides, FFA and other oil-soluble components that are more polar than the triglycerides. According to Jacobson (36), TPC in used frying oil are composed of the total level of breakdown products from the frying process.

Several workers believe that at a concentration of 25–27% TPC a frying oil has deteriorated and should be discarded (34). However, several factors should enter into consideration before arriving at this decision. In the standard method for TPC (7), the silica gel used in the column must be standardized to the correct activity to achieve clean separation of the polar components from the triglycerides. Because the standard method is long and laborious, it is often modified by substitution of small solid-phase extraction cartridges for the silica column and alteration of solvent composition to affect separation between triglycerides and polar com-

TABLE 1

Methods for Measuring Oil Degradation During Frying[a]

	Reference number
Physical characteristics of oil	
Viscosity	(4)
Foam height	(5)
Color (Method Cc 13c-50)	(6)
Smoke point (Method 9a-48)	(6)
Unstable and/or volatile decomposition products	
Conjugated dienoic acids (Method Ti 1a-64)	(6)
Free fatty acid content (Method 28.032)	(7)
Peroxide value (Method Cd 8-53)	(7)
Carbonyl content	(8)
Acid value (method Cd 2.201)	(9)
Volatiles (GLC)	(10)
Nonvolatile components and/or decomposition products	
Polar components (Method 28.074)	(7)
Fatty acid analyses (Method Ce 1-62)	(6)
Iodine value (Method 28.023)	(7)
Nonurea-adduct-forming esters	(11)
Cyclic monomers	(2)
Hydroxyl value (Method Cd 4-40)	(6)
Noneluted materials (GLC)	(13)
Polymeric triglycerides by GLC (6,14,15), LC (16), GPC (17,18), and HPSEC	(19–21)
PE insoluble oxidized fatty acids	(22)
Alkaline contaminant material	(23)
Epoxy value	(24)

[a]GLC, gas–liquid chromatography; LC, liquid chromatography; GPC, gas permeation chromatography; HPSEC, high-performance size-exclusion chromatography; PE, petroleum ether.

TABLE 2

Quick Tests for Measurement of Oil Degradation During Frying

	Reference number
Volatile decomposition products	
Fritest	
Colorimetric test for carbonyl compounds	(25)
Spot test	
Colorimetric procedure for free fatty acids	(26)
Shortening Monitor Test	
Measures free fatty acid content	(27)
Nonvolatile decomposition products	
Dielectric constant (Food Oil Sensor)	
Measures indirectly increase in polar molecules	(4,28)
RAU-test or Oxifrit test	
Colorimetric test kit—reacts with total amount of oxidized compounds	(29,30)
ACM Quick Test	
Colorimetric test for alkaline contaminant materials	(31)
TPM Quick Test	
Colorimetric test for total polar materials	(32,33)

ponents (38). In such methods, the separation may not be complete because the activity of the silica gel in the cartridges is not standardized. Silica gel activity in such cartridges differs among sources and among lots within a single source. Completeness of separation between triglycerides and polar components for any method should always be confirmed by other analytical means, such as thin-layer chromatography (7).

Levels and composition of TPC have not been related to the life of a frying oil and the resulting quality of the fried food for enough oils and fats to determine recommendations for discarding. The level of TPC may be dependent not only on use history but also on composition of the frying oil. Lumley (39) reported that when TPC content was plotted vs. polymer content for unused and corresponding used oils, slopes of the line decreased with increasing degree of saturation of the oils or fats. The more unsaturated the oil, the greater the tendency to form polymeric rather than polar degradation products. Perhaps certain polar components are better related to oil degradation and quality of fried food than TPC. TPC measurement is not the most widely accepted method for determining when a frying fat should be discarded. Countries with regulations for discarding deteriorated frying fats also use other methods (37): sensory evaluation (Spain, The Netherlands, Denmark, Austria, Norway, Finaland, Switzerland, Sweden); total polar components (Spain, Austria, Switzerland, France, Belgium); polymeric content (The Netherlands, Belgium); smoke point (Denmark, Austria, Finland, Belgium, Japan, Switzerland). Sensory evaluation of flavor and odor of frying oil and/or fried food is still the ultimate test recognized by most countries that have regulations that define when a frying oil should be discarded. Measurements, such as the concentration of TPC (25–27%) or polymeric content (<10 or <16%), or physical tests, such as smoke point (≤170°C), are often used in combination with the sensory evaluation to determine when a frying oil/fat should be discarded (37).

Relation of TPC to other oil degradation measurements. The concentration of TPC has been related to flavor quality of fried foods. Pokorny (40) published a graph of the flavor score of fried doughnuts vs. TPC concentration of oil in which they were fried (Fig. 2). The time unit was not identified, but the TPC levels in the oil are consistent with the time expressed in days. The flavor score of the first doughnuts fried in the oil at time 1 was lower than that of doughnuts fried at times 2 and 3. However, during times 1–3, the TPC concentration did not change much. During times 3–8, the flavor score did not change much, but the TPC concentration increased from 4 to approximately 12%. As the TPC content increased above 15%, the flavor score of the doughnuts decreased.

From different reports (12,37,39–41) it is possible to relate concentration ranges of TPC to frying oil life: unused oil and induction period, typically heated for 4 h at 180°C (2% < TPC < 7%); optimum frying and flavor development, dependent upon food fried (7% < TPC <20% with length of period increased by oil replenishment); deteriorated (TPC > 25–27% with oil rejected). The induction time is the heating time necessary to develop oxidation products necessary to optimize flavor and color in the fried product. Usually 3 to 4 h heating at 180°C is sufficient for the induction period, and during this period the TPC content is between

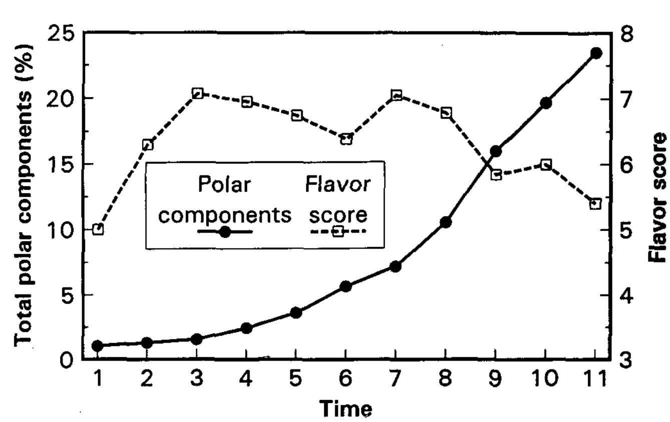

FIG. 2. Relationship between flavor scores of fried doughnuts and total polar components of frying oil over increasing frying time (Ref. 40).

2 and 7%. During the period in which an oil has optimum frying and flavor development, the TPC concentration is between 4 and 20%. Oil replenishment lengthens this optimum period. Poulmeyrol (41) has recommended that oil should be replenished for frying french fries when the TPC concentration is greater than 20%. The oil is considered deteriorated and should be discarded when the TPC concentration is greater than 25–27% (37). These TPC concentrations, however, are only guidelines and are not absolute values. Flavor formed in fried foods and the desirability of that flavor to consumers is complicated by many factors.

Flavor volatile formation during frying. Figure 1 shows that the greatest number of different types of volatiles (alcohols, aldehydes, acids, hydrocarbons, ketones, etc.) are formed *via* oxidation. The different volatiles formed and their concentrations determine the flavor of fried foods and their sensory value. Thus, anything that affects the types of volatiles formed or their concentration strongly influences the sensory value of the fried foods. These factors include the frying conditions such as time, temperature, frying equipment, additives and replenishment practices.

Fresh vs. degraded frying fat. In an investigation at the University of Tennessee (Knoxville, TN), fat samples (95:5, w/w, hydrogenated soybean oil/beef tallow) were obtained daily from each of eight fryers used for frying a variety of foods, including potatoes and breaded fish, in a restaurant during a three-week period (42). Every seven days for three weeks, fat discarded from the fryers as well as unused fresh fat were obtained for analyses, which included sensory, FFA (9), dielectric constant by the Food Oil Sensor (FOS) (22,23), TPC (7), the Hunter color values "L," "a," "b" and the overall color difference (ΔE) between unused and used fat samples (4). For a selected group (n = 54) of samples, representing the entire range of TPC found in all fat samples collected, linear correlation coefficients were determined between TPC and FFA level, FOS and ΔE. For the sensory analyses, breaded codfish samples were fried in the unused fat and in three samples of discarded fat and evaluated by a 77-member untrained panel for likability of color, flavor and overall acceptability on an 8-point hedonic scale, where 1 = dislike extremely, 2 = dislike very much, 3 = dislike moderately, 4 = dislike slightly, 5 = like slightly, 6 = like moderately, 7 = like very much and 8 = like extremely.

Significant linear relationships were found between TPC and FFA (r = 0.92, $P < 0.01$), TPC and FOS (r = 0.90, $P < 0.01$) and TPC and ΔE (r = 0.84, $P < 0.01$)(Fig. 3). The correlation coefficients found between TPC and FFA and between TPC and FOS values agreed with those of Smith and co-workers (43). Contrary to our results and those of Smith *et al.* (43), Croon *et al.* (29) found a low nonsignificant correlation coefficient between TPC and FFA. Fritsch (1) also concluded that FFA concentration was an inaccurate measurement of heat abuse of frying oils. However, Jacobson (36) reported that flavor scores for chicken fried in hydrogenated vegetable oils became marginal at an FFA of approximately 1.5%, after which changes in viscosity, refractive index and iodine values (IV) occurred much more rapidly. Therefore, the value of FFA content as a measurement of degradation in frying oils and of fried-food quality is controversial. Certainly, it is true that the FFA are volatile and can be lost *via* steam distillation. During frying and heating, FFA also degrade to more volatile compounds as well as react to form nonvolatile compounds. Therefore, whether or not FFA levels are indicative of frying oil degradation and also related to fried-food quality most likely depends upon the type of oil/fat used for frying and the frying practices utilized.

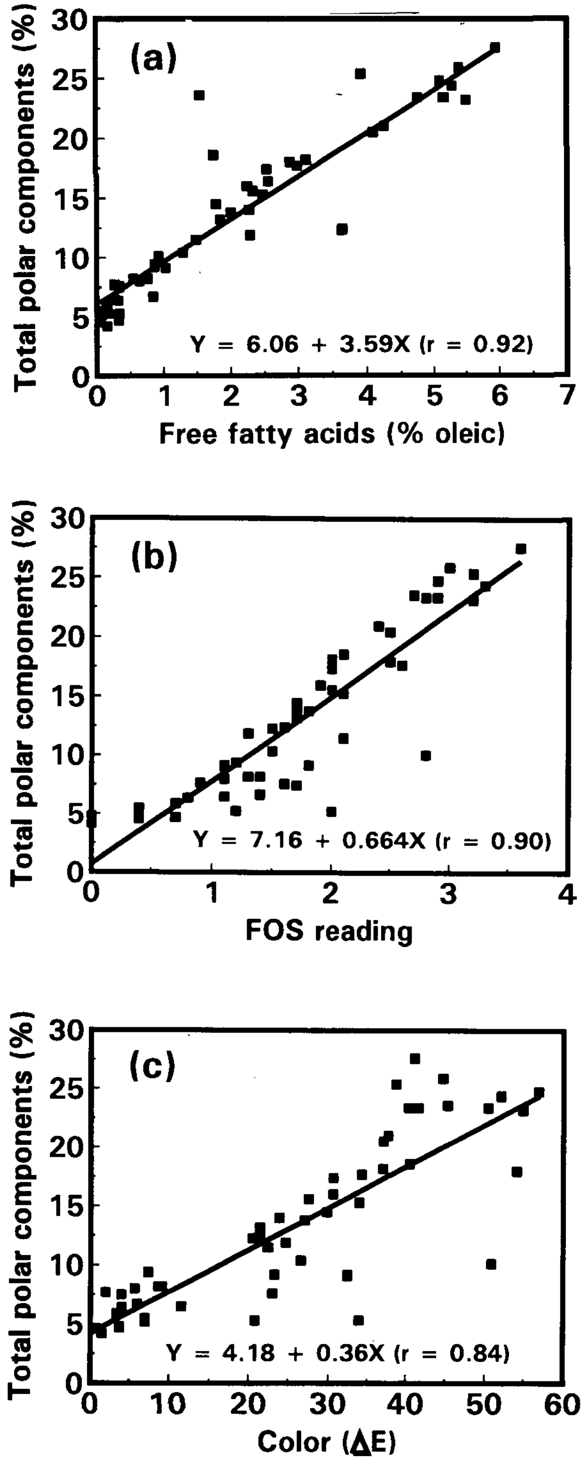

FIG. 3. Relationships of total polar components with other measures of oil deterioration: (a) free fatty acid level vs. total polar component concentration in a commercial fat over frying time (n = 54), (b) food oil sensory reading (FOS) vs. total polar component concentration in same frying fat (n = 54), and (c) color difference (ΔE) vs. total polar component concentration in same frying fat (n = 54) (Ref. 42).

The sensory scores of the breaded codfish, fried in the unused fat and in the discarded frying fats, are shown in Figure 4. The discarded fat samples had an average FFA content of 4.95% and TPC concentration of 23.9%. No significant differences existed among oil samples in the color, flavor or acceptability scores of the codfish when the entire panel (n = 77) was considered (Fig. 4a). However, some panelists (n = 29) liked the flavor of the codfish fried in the fresh unused fat, which influenced their overall acceptability scores (Fig. 4b); while other panelists (n = 24) disliked the flavor of the codfish fried in the unused fat (Fig. 4c), and other panelists (n = 24) liked the flavor of codfish fried in unused and discarded fat equally well (Fig. 4d).

Frying fat affects flavor of fried foods directly through absorption into the pores of the substance and adsorption as a film on the surface, so that fried foods contain a higher percentage of fat, making them more palatable. Various chemical reactions and their products also modify the flavor of fried foods (40). In general, oxidation products, such as alkanals, 2-alkenals and 2,4-alkadienals, all with 7 to 11 carbons, are most likely to affect the sensory quality of frying oil (44). Therefore, studies in which degradation of frying oil is measured in combination with sensory evaluation of the fried products and the analyses of their flavor volatiles are valuable in understanding the oil oxidation state and products important to fried flavor.

Flavor of foods fried in different oils/fats. In another study at the University of Tennessee (45), the frying performance of soybean oils and palm olein was investigated in combination with sensory and chemical evaluation of the flavor of fried potatoes. Each oil was heated for 1 h at 190°C prior to being used for frying food. Parfried potatoes were fried in partially hydrogenated soybean oils with IVs of 94 (soybean oil A) and 112 (soybean oil B) or in palm olein in separate fryers every hour for 8 h/d for four consecutive days. Each frying oil was sampled, filtered and replenished daily. Oil samples were analyzed for FOS, FFA and TPC. The first potatoes fried in each oil on day one (0-day) and at the end of each day of frying were analyzed by an unexperienced 32-member sensory panel for flavor desirability on a 7-point hedonic scale, where 1 = extremely undesirable flavor, 2 = very undesirable flavor, 3 = slightly undesirable flavor, 4 = slightly desirable flavor, 5 = moderately desirable flavor, 6 = very desirable flavor and 7 = extremely desirable flavor. Potatoes fried at the end of days 1 and 4 were also analyzed for flavor volatiles extracted from the potatoes by simultaneous distillation extraction (SDE). Results were analyzed by General Linear Models (46) as a function of oil type (TYPE) (soybean oil A, soybean oil B and palm olein), length of time that the frying oils were used (TIME) (days 1, 2, 3 and 4 or days 1 and 4 for volatiles) and their interaction, TYPE × TIME. Significantly different means were separated through a multiple range test or orthogonal polynomials (46).

The FFA content was affected ($P < 0.05$) by TYPE, TIME and TYPE × TIME. FFA levels increased linearly from 0.0 to 1.65 in palm olein (Fig. 5a), during 0 to 4 d of frying use, and curvilinearly from 0.01 to 1.31 in soybean oil A and from 0.02 to 1.06% in soybean oil B. The FOS reading was affected ($P < 0.05$) by TIME but not by TYPE or the interaction TYPE × TIME. Averaged across type of frying oil, the FOS reading increased from 0 to 1.7 units during the four-day frying period (Fig. 5b). TPC content was affected ($P < 0.05$) by TYPE and TIME but not by their interaction.

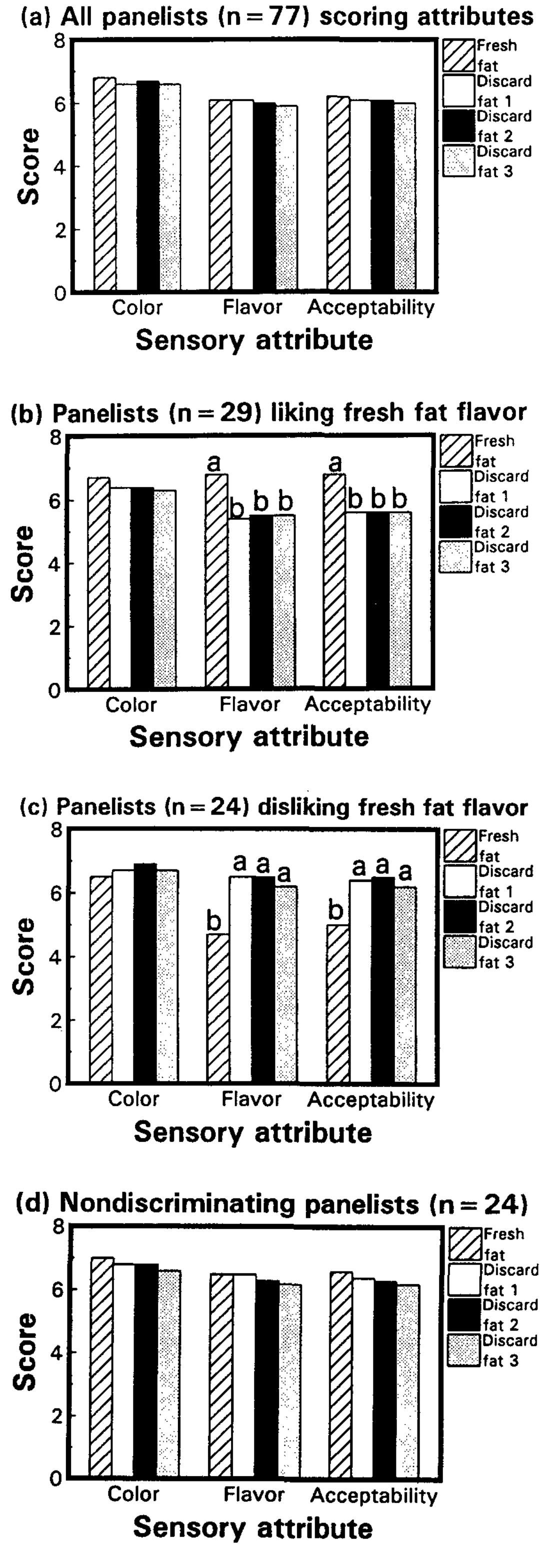

FIG. 4. Sensory scores (8-point scale) for color, flavor and acceptability of codfish fried in fresh and discarded, commercial frying fats for (a) entire panel (n = 77), (b) for panelists (n = 29) liking fresh-fat flavor, (c) for panelists (n = 24) disliking fresh-fat flavor and (d) nondiscriminating panelists (n = 214) (Ref. 42). Sensory scale: 1 = dislike extremely, 2 = dislike very much, 3 = dislike moderately, 4 = dislike slightly, 5 = like slightly, 6 = like moderately, 7 = like very much and 8 = like extremely. For any one attribute, columns bearing unlike letters are different ($P < 0.05$).

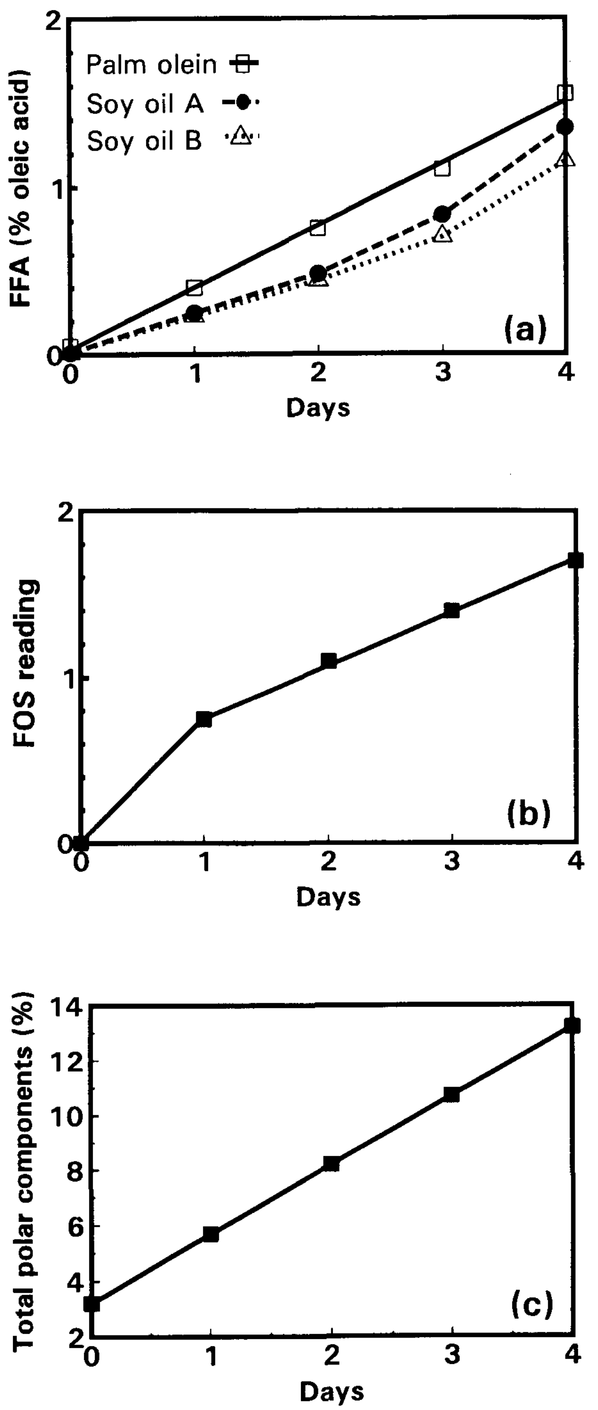

FIG. 5. (a) Free fatty acid (FFA) content of each oil used for frying french-fried potatoes, (b) mean Food Oil Sensor (FOS) readings averaged across the three frying oils; and (c) mean total polar components concentrations averaged across the three oils (Ref. 45).

Averaged across TYPE, TPC content increased linearly from 3.2 to 13.2% during 0 to 4 d of frying use (Fig. 5c). The lack of a significant interaction between TYPE and TIME indicates that TPC levels increased in each oil at a similar rate with increasing frying time use. However, when averaged across frying time, palm olein contained 10.8% TPC, which was significantly higher than the 7.1% TPC for soybean oil A or 6.7% TPC for soybean oil B. TPC content was not different ($P < 0.05$) between the two soybean oils. The higher level of TPC in palm olein was due, in part, to the higher FFA content (Fig. 5a) than in the soybean oils.

The flavor desirability score of the potatoes fried in each oil was dependent upon the oil in which they were fried and the time at which they were fried (Fig. 6). The flavor desirability score for potatoes fried in soybean oil A (IV = 94) decreased slightly from 4.5 to 4.1 with increasing frying time. The flavor desirability score for potatoes fried in soybean oil B (IV = 112) did not change significantly across days of frying oil use and was between slightly and moderately desirable (4.2). The flavor of potatoes fried at day 0 in palm olein was the least desirable of all potatoes (Fig. 6), but the flavor desirability of potatoes fried in the palm olein increased with increasing days of frying to a similar flavor score as that for the potatoes fried in the soybean oils.

The sensory panel (n = 32) that evaluated the flavor of the french-fried potatoes was divided in which oil flavor they found more desirable. Averaged across days of frying, 15 panelists found the flavor of potatoes fried in palm olein more desirable than those fried in soybean oil A (Table 3). However, the remaining members (n = 17) found the flavor of potatoes fried in either soybean oil more desirable than that of potatoes fried in palm olein. In another study at the University of Tennessee, in which the flavor of potatoes fried in soybean oil, beef tallow and palm olein in a restaurant

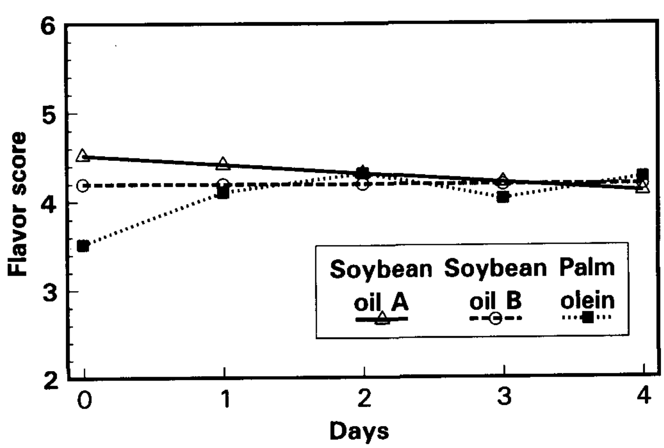

FIG. 6. Sensory scores (7-point scale) of french fries fried in different oils during increasing time of oil use (Ref. 45). Sensory scale: 1 = extremely undesirable flavor, 2 = very undesirable flavor, 3 = slightly undesirable flavor, 4 = slightly desirable flavor, 5 = moderately desirable flavor, 6 = very desirable flavor and 7 = extremely desirable flavor.

TABLE 3

Mean flavor scores[a,b] of potatoes fried in three different oils (45)

Panel type	Soybean oil A	Soybean oil B	Palm olein
Total (n = 32)	4.3c	4.2c	4.0d
Panel A (n = 15)	4.1d	4.3cd	4.6c
Panel B (n = 17)	4.4c	4.2c	3.6d

[a]7-point scale where 3 = slightly undesirable; 4 = slightly desirable and 5 = moderately desirable.
[b]Means in a row followed by unlike letters are different ($P < 0.05$).

was investigated, similar results were found in a sensory panel of nearly 2,000 people (47). Part of the panel liked the flavor of potatoes fried in beef tallow much better than those fried in palm olein, but others preferred the flavor of the potatoes fried in palm olein over that of potatoes fried in beef tallow. The flavor score for potatoes fried in the soybean oil was always scored between that of potatoes fried in the other oils/fats. The observed difference was dependent upon the gender of the panelists. Males liked the flavor of potatoes fried in beef fat more than those fried in palm olein; females liked the flavor of potatoes fried in palm olein the best. The fact that differences exist among frying oils/fats on the sensory quality of fried foods is not disputed (40), but little information is available concerning how habits, custom, gender, etc. affect consumer preference for the flavor of one oil compared with another.

In reality, the flavor of fried foods depends upon the flavor volatiles present and their concentration. In the study in which the flavor desirability score of potatoes was affected by TYPE, TIME and TYPE × TIME (45), concentrations of flavor volatiles extracted by SDE were also affected ($P < 0.10$) by TIME and TYPE but not TIME × TYPE interaction. Therefore, volatile concentrations, averaged across types of oils for days 1 and 4 of oil use as shown in Table 4, can be compared, as well as the volatile concentrations that were averaged across use time for each oil as given in Table 5. In general, either no differences were found between days 1 and 4 in the concentrations of the volatiles, or the volatile concentration was decreased by using the oil for a longer time. Compared with the 2-alkenals, more heterocyclic compounds decreased in concentration with increased use of the frying oils (Table 6).

Table 5 shows the concentrations of selected volatiles in potatoes fried in the three different oils. Soybean oil B, which had a higher percentage of linoleic acid (18:2) than the other oils, produced fried potatoes with higher concentrations of 18:2 oxidation products, the 2,4-decadienals. Soybean oil B also had the highest level (%) of linolenic acid (18:3), and potatoes fried in soybean oil B had the highest levels of *t,t*-2,4-heptadienal, an oxidation product of 18:3 (Table 5). Soybean oil A, soybean oil B and palm olein had initial concentrations of 60.52, 55.7 and 42.7% oleic acid (18:1), respectively. However, the potatoes fried in soybean oil A did not have the greatest concentrations of the oxidation products of 18:1, the volatile 2-alkenals, but rather the potatoes fried in soybean oil B did. Potatoes fried in soybean oil B had higher concentrations of *t*-2-octenal, *t*-2-nonenal and *t*-2-undecenal than potatoes fried in the other oils (Table 5). The extent to which the differences in the concentrations of the potato volatiles influenced the flavor scores shown in Figure 6 and Table 3 is unknown. In general, *t,t*-2,4-decadienal imparts good fried flavor when added to fresh edible oil (40). On the other hand, increasing concentrations of this aldehyde have been correlated with increasing flavor intensity of soybean oil that was oxidized during a modified Schall oven test at 60°C by Warner and Frankel (48). Among the frying oils examined in our study, soybean oil B produced fried potatoes with the highest concentration of *t,t*-2,4-decadienal, yet potatoes fried in soybean oil B did not have any more desirable flavor than potatoes fried in soybean oil A (Table 3). Perhaps, the higher concentrations of the 2-alkenals in soybean oil B-fried potatoes than those fried in soybean oil A detracted from the flavor desirability added by the higher concentration of *t,t*-2,4-decadienal. It could also be possible that, above a certain concentration, *t,t*-2,4-decadienal does not contribute to fried-food flavor. A desirable deep-fat fried flavor is dependent not only on the type and concentration of volatiles present but also on the type of oil used, its fatty acid composition, the frying conditions used, the food fried and the consumers who perceive the flavor.

The frying process shown in Figure 1 is a complicated thermal chemical process that produces fried foods with desirable color, flavor and texture. To expect a simple relationship between oil composition, stability and desirable sensory qualities for every food fried and every oil/fat used in frying appears unreasonable. Likewise, to have a single method that determines when frying oils have deteriorated and should be discarded may not be practical. The measurement of TPC may have advantages over methods that measure volatile and/or unstable degradation products in frying oil and likely accounts for adaptation of TPC as a

TABLE 4

Mean Concentration[a,b] of Selected Volatiles Isolated from Potatoes at the End of Day 1 and Day 4 of Frying Oil Use (45)

Volatile	Frying day 1	Frying day 4
2-Methylpyrazine	0.018a	0.007b
2,5-Dimethylpyrazine	0.092a	0.064b
2,6-Dimethylpyrazine	0.007a	0.002b
2,3,5-Trimethylpyrazine	0.013a	0.005b
Nonanal	0.012	0.015
t-2-Octenal	0.013	0.014
Benzaldehyde	0.006a	0.004b
t,t-2,4-Heptadienal	0.002	0.002
t-2-Nonenal	0.011	0.009
t-2-Decenal	0.029	0.032
Phenylacetealdehyde	0.079	0.047
t-2-Undecenal	0.002a	0.001b
c,t-2,4-Decadienal	0.013a	0.011b
t,t-2,4-Decadienal	0.072a	0.052b

[a]Mg equivalents methyl palmitate/150 g potatoes.
[b]Means (n = 6) in a row followed by unlike letters are different ($P < 0.10$).

TABLE 5

Mean Concentrations[a,b] of Selected Volatiles Isolated from Potatoes Fried in Different Oils Averaged Across Use Time of Frying Oils (45)

Volatile	Soybean oil A	Soybean oil B	Palm olein
2-Methylpyrazine	0.014x	0.017x	0.004y
2,5-Dimethylpyrazine	0.075	0.116	0.043
2,6-Dimethylpyrazine	0.006	0.004	0.004
2,3,5-Trimethylpyrazine	0.013	0.011	0.004
Nonanal	0.011	0.018	0.012
t-2-Octenal	0.012y	0.021x	0.007y
Benzalddehyde	0.004y	0.007x	0.004y
t,t-2,4-Heptadienal	0.002xy	0.004x	0.001y
t-2-Nonenal	0.006y	0.014x	0.008xy
t-2-Decenal	0.033	0.026	0.033
Phenylacetaldehyde	0.068	0.076	0.046
t-2-Undecenal	0.001y	0.002x	0.001y
c,t-2,4-Decadienal	0.011y	0.017x	0.008y
t,t-2,4-DDecadienal	0.055y	0.091x	0.040y

[a]Mg equivalents methyl palmitate/150 g potatoes.
[b]Means (n = 4) in a row followed by unlike letters are different ($P > 0.10$).

quick method (32,33). However, it still has not been proven that, at a given TPC concentration, all frying fats have deteriorated to the point where fried foods have inferior sensory quality or contain components hazardous to health. More research is needed to explore the relationships for the different types of frying fats used and the different foods fried in correlating level of TPC with sensory quality of foods fried in them. It is only when levels of TPC are correlated with sensory quality of fried food and related to the concentration of components known to have antinutritional effects that we will have evidence to substantiate this claim.

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