Changes in Physical and Chemical Properties of Shortenings Used for Commercial Deep-Fat Frying[1]

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This study evaluated some of the changes that occur in shortenings used for commercial deep-fat frying in fast-service restaurants. Foods cooked in partially hydrogenated soybean oil were battered chicken parts and french fries. Sixty-five samples of fresh and used shortenings were collected from nine restaurants on three occasions over a three-month period. Frying periods varied from 0 to 300 hr, and most samples were taken just before the used fat was discarded. For fresh shortenings, percentages of polar materials, free fatty acids (FFA), materials not eluted by gas chromatography, and fatty acid profiles differed only slightly. For used samples, there were marked variations in these analyses and in increases of dielectric constant measurements. Frying times were highly correlated with increases in dielectric constant, polar materials and FFA. The greatest change in fatty acid profiles occurred in *trans*-C18 monoenes which decreased from over 40% to as low as 13%. Due to lipid exchange with chicken fat, both oleic and linoleic acids increased in the shortenings with hours of use, whereas stearic acid decreased. There were high correlations among increases in dielectric constant, percentages of polar materials and FFA, demonstrating that each of these methods could predict degradation of the shortening. However, the increase in dielectric constant, as measured by a Foodoil Sensor (FOS), was the most convenient for quality control in restaurant situations. In most cases, used shortening was discarded before 100 hr of frying time; and only a few of these samples had FOS readings near 4.0, FFA over 1.00%, or percentages of polar materials over 27%. These values have been suggested as discard criteria. However, a number of samples used between 100 and 300 hr exceeded these limits. There is a need to specify suitable limits, related to quality and health factors, to determine at what point a cooking fat should be discarded.

Consumption of food fats (both visible and invisible) has increased to around 130 lb per person annually in the U.S.A. This greater consumption may be attributed partly to the changing eating habits of Americans. Convenience and snack foods have risen sharply in popularity, and about one-third of all meals are now eaten away from home. Restaurant use of fats and oils rose 69% between 1969 and 1979 and accounted for 19.7% of visible fats and oils consumed in 1982 (1). Growing numbers of fast-food outlets specializing primarily in deep-fat fried foods such as chicken, fish and french-fried potatoes account for the increased use of cooking fats and oils. These foods absorb substantial amounts of the fat used for deep-frying (2).

During cooking, the fat or oil often is kept hot (about 180 C) for long periods of time and is exposed to both moisture and oxygen. Complex chemical and physical changes occur under these conditions, causing fat deterioration which may reach a point where the flavor, odor, color, nutritional value and safety of the food may be affected (3,4). While much research has been expended in the study of the mechanisms and products of fat deterioration (5,6) under laboratory conditions, relatively little information is available on the changes that occur in cooking fats and oils during use in restaurants and other establishments. Thompson and Aust (7) have discussed the importance of considering differences in conditions used in laboratory studies when compared to commercial deep frying of foods.

The objectives of this study were to study the composition of fresh and used shortenings from California restaurants and fast-food outlets, and to evaluate relationships among the physical and chemical data obtained.

EXPERIMENTAL PROCEDURES

Sampling. Cooking shortenings were obtained from fast-food restaurants serving fried chicken and french fried potatoes in the Sacramento area. These two items represent the greatest volume of deep-fat fried foods in the U.S.A. Sixty-five samples of fresh and used shortenings were collected from nine fast-food restaurants that included Church's Fried Chicken, Picnic N' Chicken, Pioneer Fried Chicken and Kentucky Fried Chicken. Most of the used shortening samples were obtained just prior to being discarded. Each restaurant provided the following information: foods cooked; type of frying shortening; conditions of usage including temperature, hours per day, days used, make-up percentage, type of filter and frequency of filtration. All restaurants used partially hydrogenated soybean oil (PHSO) shortenings containing dimethylpolysiloxane (antifoam agent) and generally referred to commercially as "heavy duty cooking fats." Collections of fresh and used fat from each restaurant were made on three separate occasions over a period of approximately three months. Samples of fresh shortenings were obtained and put directly into four-oz screw-cap bottles. Hot used shortening samples were obtained directly from the frying cookers with aluminum sampling pans; they were taken at a depth of approximately three inches below the surface. Sampling was not done during actual food frying to avoid including moisture. Samples were allowed to cool and then were transferred to polyethylene bottles. At the laboratory, all samples were transferred to glass bottles, flushed with nitrogen and stored at −4 C until analyzed within 1-3 weeks.

Analysis of shortenings, dielectric constant measurements. Increases in the dielectric property of the used

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shortenings were estimated (8) with a Foodoil Sensor (FOS) model NI-20 (Northern Instruments Corporation, Lino Lakes, Minnesota). Procedures for calibration with fresh fat and analysis were the same as in the operation manual. Results are expressed as FOS readings (Table 1) or as Increase in Dielectric Constant (Figs. 1 and 2).

Polar materials. Percentages of total polar materials were determined by the silica gel column chromatographic method of Billek et al. (9).

Free fatty acids. Percentages of free fatty acids (FFA) were determined by alkaline titration according to AOAC methods (10) and were expressed as oleic acid percentages.

Fatty acid composition. Fatty acids were determined by gas liquid chromatography (GC) of methyl esters prepared by the procedure of Metcalfe et al. (11). Instrumentation and conditions for GC included a Hewlett Packard Model 5711A gas chromatograph with a flame ionization detector and a 610 × 0.257 cm ID stainless steel column packed with 15% OV-275 (Supelco Inc., Bellefonte, Pennsylvania) on high performance Chromosorb W. The column was operated isothermally at 220 C, injector temperature at 225 C and detector temperature at 240 C. Nitrogen carrier gas flow rate was 12 ml/min. Standard mixtures of fatty acid methyl esters or of simple triglycerides (Nu-Chek Prep, Elysian, Minnesota) were used to obtain relative retention times and response factors for calibration of the Hewlett Packard 3352E data system. Triheptadecanoin was used as the internal standard to determine percent noneluted materials as described by Waltking et al. (12). Results for used fats were corrected for amounts of components not eluted from the GC column. Averages of at least two separate analyses of fatty acid composition for each shortening were reported.

The ratio of unsaturated to saturated fatty acids (unsat./sat.) included total identified unsaturated and total identified saturated components.

Statistical analysis. The data were analyzed by correlation and regression analyses (13) of complete data sets using the Minitab system (14). Individual data points as well as a least-square fitted line of all data points were plotted.

RESULTS AND DISCUSSION

The fresh PHSO shortenings used by the four different fast-food chains in their franchise restaurants were very similar in composition (Tables 1 and 2). FOS readings of fresh unused shortenings were set at zero to permit measurement of increased dielectric constant with deterioration as the shortenings were used. Percentages of polar materials, free fatty acids and noneluted materials in the fresh shortenings differed only slightly. Similarly, the profiles of major fatty acids varied within narrow ranges.

For the used shortenings, results of the physical and chemical analyses (Tables 1 and 2) ranged widely, indicating marked variation in the degree of deterioration and extent of lipid exchange between the food and the shortening. Differences in the conditions of usage between fast-food chains and between individual restaurants of the same chain accounted for the above variation. In general, the longer the shortening was used, the greater was the deterioration and lipid exchange. Although similar foods (battered chicken parts and frozen partly fried french fried potatoes) were deep-fried, there was considerable variation in food volumes, cooking temperatures, hours of cooking per day, shortening make-up percentages per day, type of filter and frequency of fat filtration between chains and individual restaurants. The amount of make-up fat was particularly important when the fat was used longer than 100 hr because of dilution effects. In most cases the shortening was discarded before 100 hr of frying time. However, the addition of fresh shortening as required from day to day would be expected to reduce the deleterious effects of deep-frying. This probably accounts for much of the "spread" of the data points in Figure 1. Also, it is important to note that the correlations shown in Figures 2 and 3 were based on data from shortenings used from zero to 300 hr of frying. The relationships between hours of frying use (up to 100 hr) and the results of several physical and chemical analyses were determined. Figures 1A, 1B and 1C show good correlations between frying times and increases in dielectric constant (R = 0.84), percentages of polar material (R = 0.80), and percentages of free fatty acids (R = 0.88). The greatest changes in fatty acid profiles occurred with *trans*-C18 monoenes (elaidic acid in Fig. 1H), which decreased with hours of use (R = −0.69). Palmitic acid (Fig. 1D) increased (R = 0.69) but stearic acid (Fig. 1G) decreased (R = −0.66). Both oleic acid (Fig. 1E) and linoleic acid (Fig. 1F) increased with hours of use (R = 0.40 and R = 0.60, respectively).

Changes in the composition of shortenings used to deep-fry both partially fried french fried potatoes and chicken parts have not been reported in the literature. Thompson and Aust (7) studied the changes in the compositions of a lightly hydrogenated frying oil and of french fries prepared in a short-order restaurant. After 100 hr of frying, total linoleic and linolenic acids dropped 50%. In the present study, linoleic acid increased significantly during the same period because chicken fat rich in this acid was extracted into the frying shortening

TABLE 1

Physical and Chemical Analyses of Fresh and Used[a] PHSO Shortenings

	Shortening			
	Fresh (9)[b]		Used (56)[b]	
	Range	Mean	Range	Mean
FOS Reading[c]	0	—	0.25- 4.85	2.05
Polar Materials (%)	1.0 -2.8	2.5	3.4 -36.6	16.4
Free Fatty Acids (% oleic acid)	0.04-0.05	0.04	0.09- 1.54	0.76
Non-eluted Materials (%)	0 -1.2	0.7	0.5 -14.2	6.1

[a]Used to deep-fry chicken pieces and french fried potatoes at 168-191 C for 12-300 hr.
[b]Number of samples analyzed.
[c]Determined with a Foodoil Sensor model NI-20.

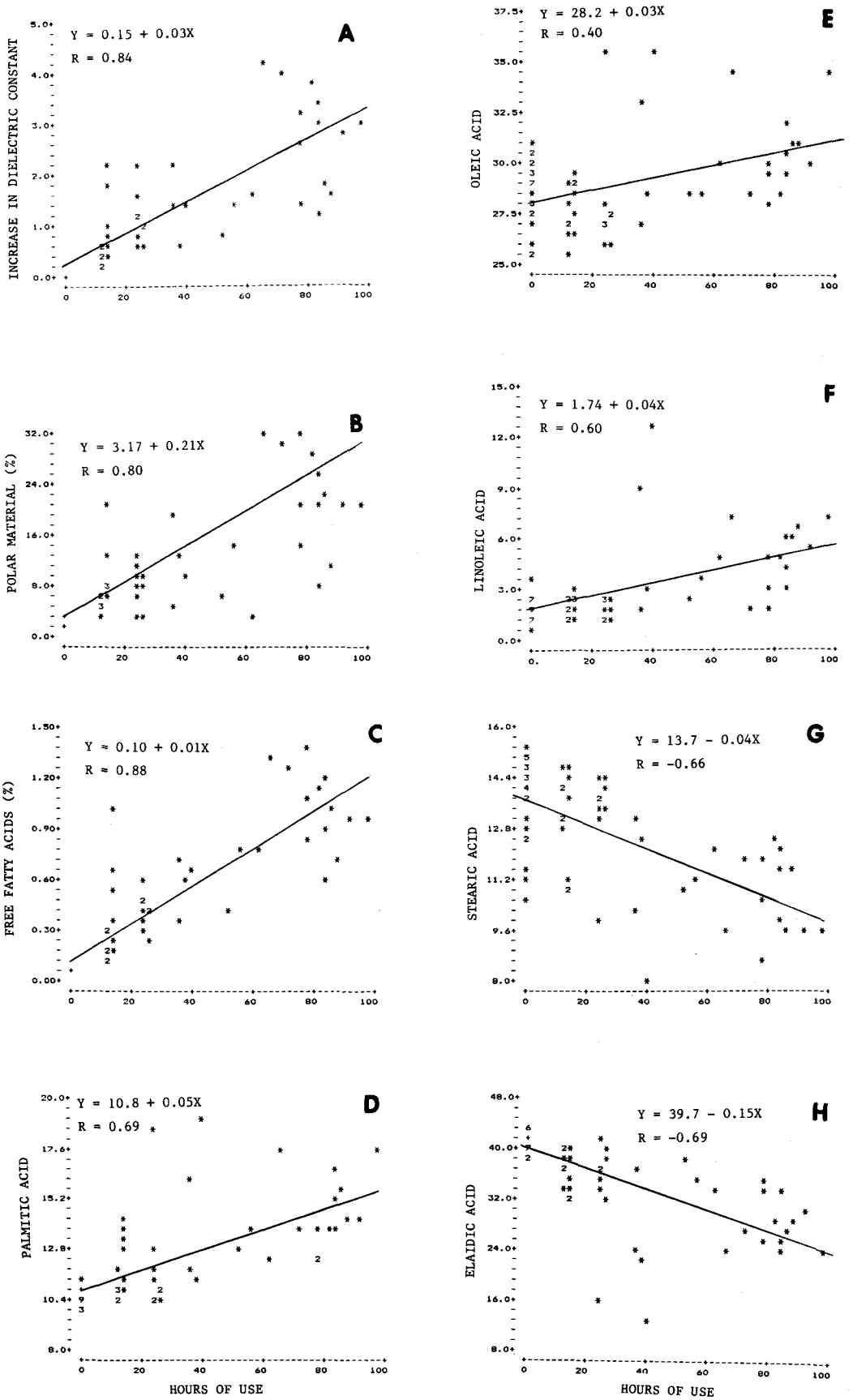

FIG. 1. Changes in physical and chemical properties (ordinate) of shortenings used for frying chicken pieces and french fries over 0 to 100 hr frying periods (abscissa). Analytical methods are described in the text. Each point is plotted with the symbol *, but when more than one point fell on the same plotting position, a count of the number of points falling there is given. When more than 9 points fell on the same plotting position, the symbol + is used.

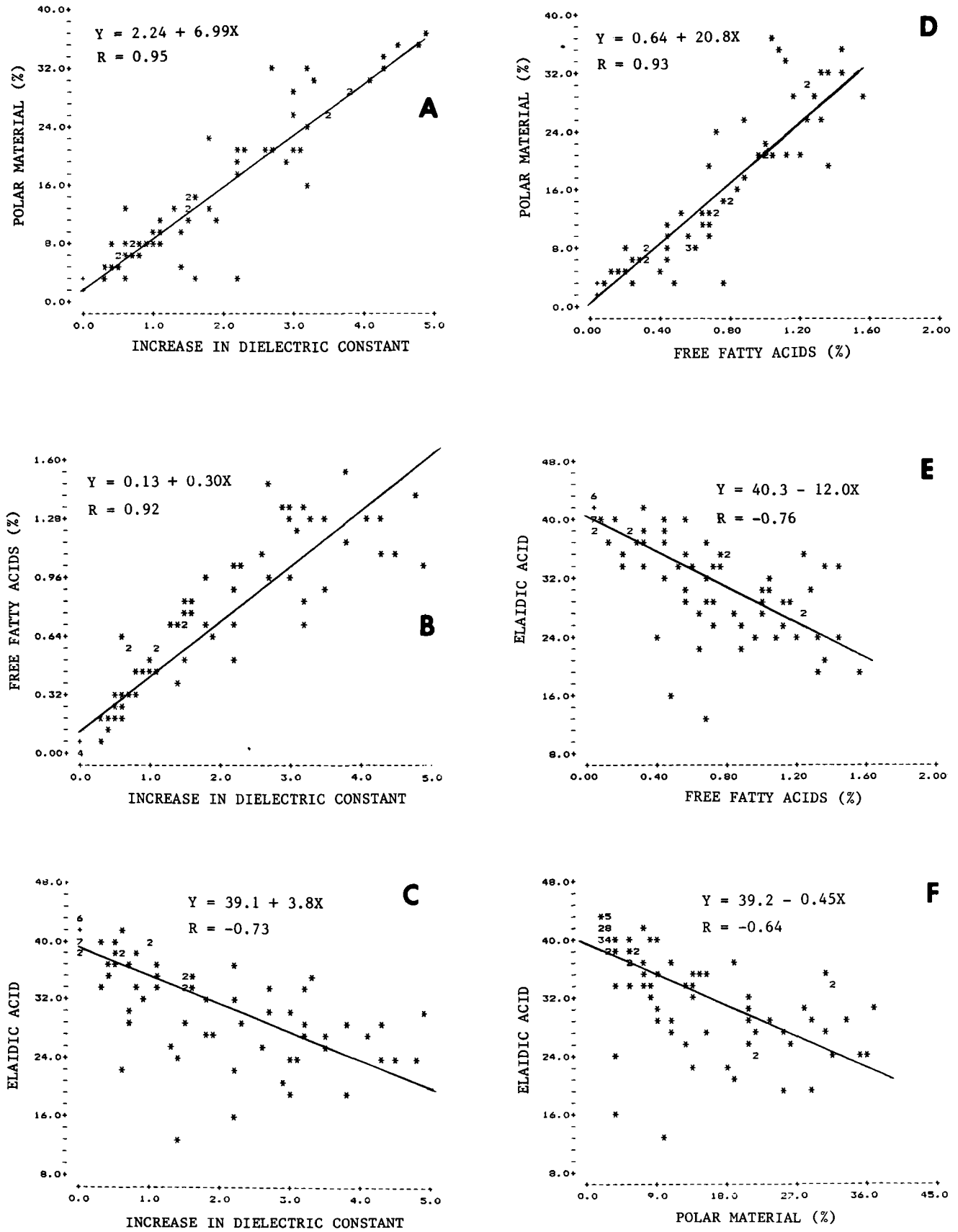

FIG. 2. Relationships among physical and chemical data obtained by analyses of shortenings used for frying chicken pieces and french fries over 0 to 300 hr frying periods. Analytical methods are described in the text. See Fig. 1 for explanation of figure symbols.

TABLE 2

Fatty Acid Composition (Weight Percent) of Fresh and Used[a] PHSO Shortenings

Fatty acid	Shortening			
	Fresh (9)[b]		Used (56)[b]	
	Range	Mean	Range	Mean
C14:0	0 - 0.3	0.1	0.1- 0.5	0.3
C16:0	10.3-11.0	10.6	10.4-19.2	13.4
C16:1t	0 - 0.1	0.1	0 - 0.2	0.1
C16:1c	0.2- 0.3	0.2	0.2- 6.2	1.7
C18:0	11.4-14.7	13.8	8.0-14.7	11.8
C18:1t	40.4-42.3	41.4	12.8-41.2	30.6
C18:1c	27.6-29.8	28.6	22.8-35.6	29.2
C18:2ω6	1.3- 2.3	1.8	0.9-12.5	3.8
C18:3ω3	0.1- 0.2	0.1	0 - 0.8	0.3
Unsaturated/ saturated	2.9- 3.4	3.0	2.1- 3.1	2.7

[a]Used to deep-fry chicken pieces and french fried potatoes at 168-191 C for 12-300 hr.
[b]Number of samples analyzed.

(2). Thompson and Aust found total saturated fatty acids increased, primarily due to increased palmitic acid, and total *trans* fatty acids decreased. These results are in agreement with those of the present study.

The fresh shortening contained 10.6% palmitic acid, the shortening used for french fries alone had 12.6% palmitic acid and the shortening used for both french fries and chicken pieces had 15.3% palmitic acid. Thus, the oil used for blanching the french fries contributed somewhat to the increased palmitic acid in the used shortening. However, since chicken fat contains about 22% palmitic acid, exchange of this fat with PHSO shortenings probably accounted for most of the fatty acid changes observed in the used shortenings. Estimates based on the two highest levels of linoleic acid in the used shortening (Fig. 1F) show there was a maximum of about 45% chicken fat present in those two samples.

The possibility of employing the physical and chemical changes observed in the present study as quality control measures was considered. As shown in Figures 2A and 2B, there were high correlations between increase in dielectric constant (FOS reading) and both polar materials (R = 0.95) and FFA (R = 0.92). It follows (Fig. 2D) that there was also a high correlation between percentages of polar materials and FFA (R = 0.93). The decrease in elaidic acid during deep-frying was correlated negatively (Figs. 2C, 2E, 2F) with increases in dielectric constant (R = −0.73), with increases in FFA (R = −0.76) and with increases in percentage of polar materials (R = −0.64).

In some European countries, fats with FOS readings up to 4.0 are considered acceptable for continued commercial use in deep-fat frying (15). Shortenings used up to 100 hr in the present study did not exceed this FOS reading. However, some shortenings used between 100 and 300 hr gave readings between 4.0 and 5.0 and should have been discarded earlier based on this criterion.

The German Society for Fat Research defines a fat as deteriorated when it contains 27% or more polar materials (15). Only three of the shortenings used up to 100 hr exceeded 27% polar materials (Fig. 1B). Several of those used between 100 and 300 hr exceeded this level (Fig. 2A, 2D).

A common recommendation in the U.S.A. is to discard cooking fats when their free fatty acids (FFA) exceed 1.0%. A few of the shortenings used up to 100 hr exceeded this limit (Fig. 1C). Several of those used longer contained higher levels of FFA (Fig. 2B).

The greatest changes in the fatty acid profiles occurred in *trans*-C18 monoenes. Initial percentages ranged from 42.3 to 40.4% in the fresh shortening (Table 2). Percentages in the fats used for up to 300 hr ranged from 41.2 to 12.8, representing decreases up 70%.

The increase in dielectric constant (FOS reading) (8) was the only method in this study that could be employed conveniently in a fast-food restaurant. It is easy to use, fast, and fresh control fat is available in the restaurant. The admixture of chicken lipids, noted above, probably has a limited effect on this increase because fresh chicken fat had a FOS reading only 0.8 higher than PHSO. The other methods used require laboratory facilities. FFA determination (10) involves precise weighings and accurate preparation of solutions. Titration end-point is difficult to ascertain, especially with the darker-colored used fats. Estimation of polar material (9) requires special glassware, careful technique, and at least three hours to analyze each sample. Major fatty acids in fresh shortenings can be determined readily by GC of methyl esters, and this equipment is available in many quality control laboratories. However, with deteriorated used fats, polymeric materials are not eluted from the GC column. The non-eluted materials can be estimated by the internal standard GC procedure of Waltking et al. (12). This procedure requires very precise weighings, and there is difficulty in obtaining reproducible results. In our experience, the results did not correlate well with FOS readings, FFA or polar materials.

Nutritional implications. The PHSO frying shortenings analyzed in this study were representative of the group of fats commonly used in restaurant deep-fat frying operations (16). This group is frequently referred to as the "heavy duty" fats because they have been specially hydrogenated to make them resistant to oxidative changes after packaging and during the frying operation. They usually are hydrogenated to a degree that makes them fairly firm at room temperature. Soybean oil is often used to prepare these shortenings because of its lower price and ready availability.

When fats are heated in deep-frying of foods, significant chemical and physical changes occur (6). If the heating or oxidation is severe, the fats lose part of their nutritional value. Changes occurring in heated fats have been followed by a large variety of analytical methods including determination of cyclic fatty acid monomers (4,5,6,17). Precise information is not available concerning the possible effects on human health of ingesting low levels of cyclic monomers. Frankel et al. (17) analyzed a wide variety of commercial frying fats and oils including samples of PHSO shortenings obtained from the same restaurants that supplied samples for the present study. The U.S.A. cooking fats

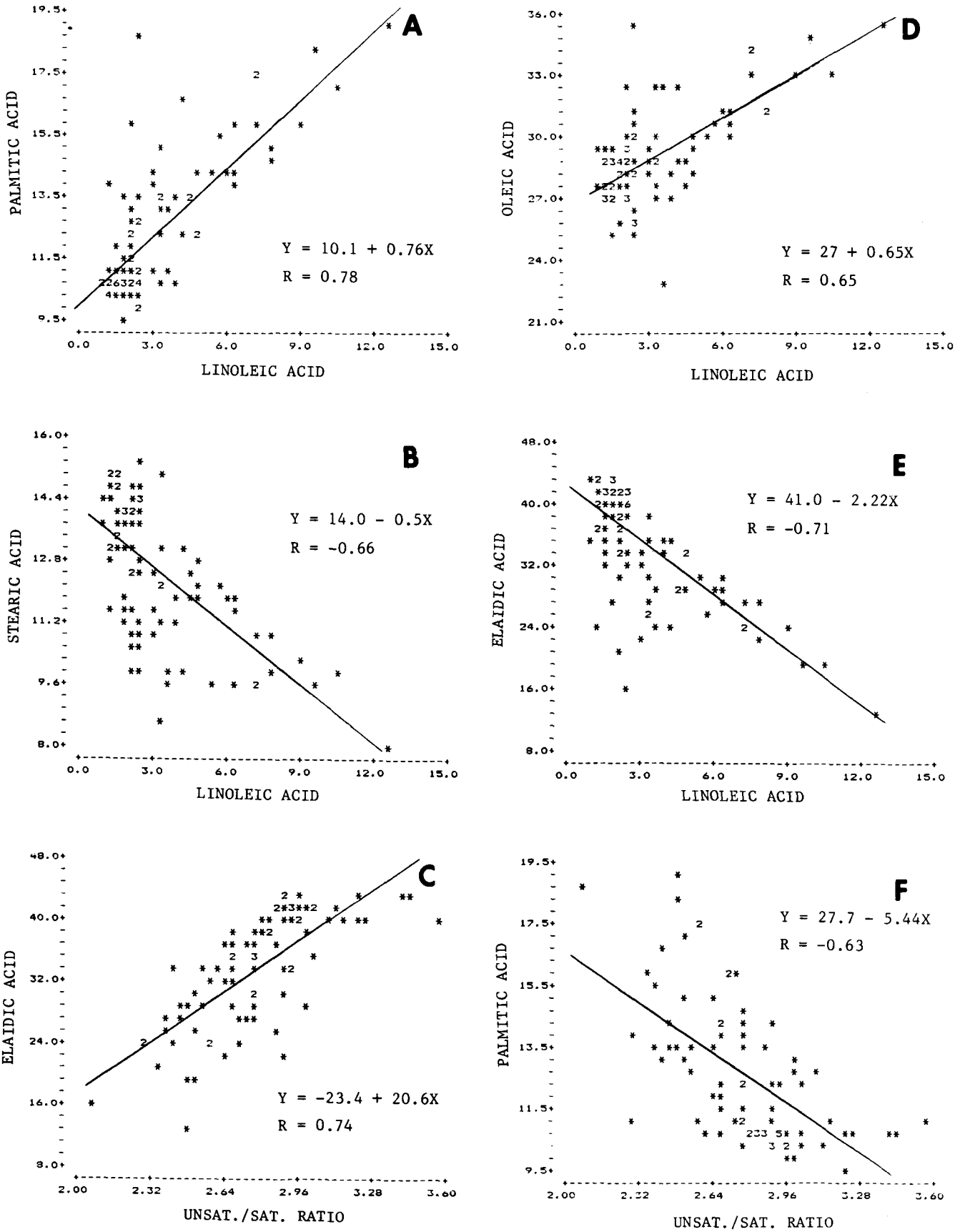

FIG. 3. Relationships among fatty acids of shortenings used for frying chicken pieces and french fries over 0 to 300 hr frying periods. Fatty acids were determined by GC as described in the text. See Fig. 1 for explanation of figure symbols.

examined by Frankel et al. contained a range of cyclic monomers only from 0.1% to 0.5%. Non-eluted materials in the present study (Table 1) did not exceed 14.2% and were usually below 10%. Presently available information suggests that it is unlikely that the above levels of cyclic monomers and non-eluted materials may have toxicological consequence when consumed in a mixed diet by humans (15,17,19).

Partial hydrogenation of soybean oil results in the formation of *trans* fatty acids with a chain length of 18 carbon atoms (Table 2). Because the metabolism and other properties of *trans* fatty acids differ from those of *cis* unsaturated isomers, they are of special interest in deep-fat frying. Firestone et al. (20) reported an increase in isolated *trans* fatty acids in cottonseed oil heated for 300 hr under laboratory conditions. In contrast, Thompson and Aust (7) found a 13% loss of total *trans* fatty acids after 100 hr of frying with a lightly hydrogenated soybean oil. In the present study, losses of elaidic during 100 hr of commercial deep-frying ranged up to 70% and averaged 22%.

The biological effects of *trans* fatty acids have been evaluated by many investigators who have employed long-term feeding experiments with several species, including man (18,21). It is generally concluded that *trans* fatty acids have not been found to have adverse effects provided sufficient linoleic acid is present in the diet.

There were considerable changes in the fatty acid composition of the PHSO shortenings over the frying period, as shown in Table 2. Only small amounts of linoleic and linolenic acids were in the fresh shortenings. Despite the effects of oxidation and heat during deep-fat frying, the amount of linoleic acid actually increased with frying time (Table 2 and Fig. 1F), due to extraction of chicken fat. Increases in linoleic acid were correlated with increases in palmitic acid (Fig. 3A), with increases in oleic acid (Fig. 3D), with decreases in stearic acid (Fig. 3B), and with decreases in elaidic acid (Fig. 3E).

The ratio of polyunsaturated fatty acids to saturated fatty acids (P/S) in dietary fats is of interest to nutritionalists. Because the fresh PHSO shortenings of this study contained only small amounts of polyunsaturated fatty acids, we preferred to calculate the ratio of total unsaturated fatty acids (mostly monounsaturated) to total saturated fatty acids (unsat./sat.). This ratio varied between 2.9 to 3.4 in the fresh shortenings (Table 2). During frying the ratio decreased to between 2.1 and 3.1. These results indicate that unsat./sat. of the shortening decreased only slightly when chicken parts and french fries were deep-fat fried. The decreases in unsat./sat. correlated well (Figs. 3C and 3F) with the decreases in elaidic acid ($R = 0.74$) and the increases in palmitic acid ($R = -0.63$).

As discussed by Stevenson et al. (4), additional information is needed to determine at what point a frying fat should be discarded. Guidelines may need to vary depending on the type of frying fat (16) and the type of food being cooked. As pointed out by Barran (22), research is needed to explore methods of extending the useful life of shortenings used for deep-fat frying.

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