Frying Oil and Fat Quality Measured by Chemical, Physical, and Test Kit Analyses

E.A.A. Sanibal and J. Mancini-Filho*

Universidade de São Paulo (USP), São Paulo, Brazil

ABSTRACT: The performance of soybean oil (SBO) and a partially hydrogenated soybean oil (PHSBO) was monitored by chemical, physical, and test kit analyses during 50 h of deep-frying of potatoes in SBO and 50 h of deep-frying of potatoes in PHSBO. The oxidative stability of SBO and PHSBO was measured by the iodine value, color index, FFA content, total polar compounds, and FA analysis of deep-frying SBO and PHSBO. SBO, with higher levels of unsaturated FA, had the faster rate of formation of geometric and positional isomers of unsaturated FA as measured by GC with standards. PHSBO performance under deep-frying conditions was significantly better than SBO with respect to iodine value, color index, and total polar compounds. The results from analyses using test kits had a good correlation with analytical parameters.

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KEY WORDS: Fatty acid, frying, partially hydrogenated soybean oil, potato, soybean oil.

Deep-fat frying is one of the most popular procedures for food preparation since it is rapid and develops desirable flavors and textures. However, using frying oils repeatedly can produce constituents that not only compromise food quality but also can promote the formation of compounds with adverse nutritional implications and potential hazards to human health. The quality and stability of frying fats are therefore of concern to food technologists, nutritionists, and consumers.

During deep-frying, oils and fats are continuously or repeatedly heated at high temperatures for long periods of time in the presence of air and some type of food. This leads to a variety of chemical reactions, which can be categorized as hydrolysis, oxidation, and polymerization of the TAG molecule. Decomposition products formed by cyclization, condensation, and scission reactions may or may not be volatile, and they may undergo further degradation (1). The choice of oil to use in frying is difficult, as factors such as stability, price, and nutritive value must be considered. Oils with a high content of saturated FA have greater stability in frying applications (2). However, these oils are undesirable from a nutritional and human standpoint (3). Frying has been suggested as a source of *trans* FA. Pozo-Diez (4) has shown that the percentage of elaidic acid in olive oil or high-oleic acid sunflower oil increases during potato frying. There is some evidence that highly oxidized and heated oils exhibit deleterious health effects when fed to laboratory animals. The observed effects range from weight loss, growth suppression, and increased liver and kidney weight to cellular damage to liver, thymus, and epidydimides (5–7).

Several analytical methods for monitoring frying oil quality have been reported, including chromatography for measurement of viscosity, dielectric constant, smoke point, and contents of polymers, carbonyls, FFA, and polar compounds; and GLC for dimers, cyclic monomers, and short-chain FA. Some of the methods are now official AOCS methods (8).

One method for evaluating the degradation of frying oil is by measuring the content of oxidized FA as petroleum ether-insolubles (9). A limit of 0.7–1% oxidized FA in frying oil was recommended in Germany as early as 1973 (1). However, analyzing petroleum ether-insoluble oxidized FA is very labor intensive. The content of total polar compounds (TPC) formed in oil, as determined by the column chromatographic method, correlated well with the content of oxidized FA. High-performance size-exclusion chromatography (HPSEC) appears to be the most useful method for the analysis of polymerized TAG. Determinations of TPC as well as the analysis of dimeric and polymeric TAG are now official AOCS methods, and determination of TPC is widely recognized as the most accurate method for assessing the degradation status of frying oils (9–12). Many European countries have established regulatory limits for TPC in frying oils. Most of these countries have set a limit of 25% TPC, and in some others, the content of dimers and polymers TAG is set at 16% (13).

More recently, several test kits have been developed to measure the degradation state of in-process frying oils. The gel-based Veri-Fry® FFA, TPM (total polar materials), and WET (water emulsion titratables) kits are mainly used by inspectorates and industrial frying plants. The solvent-based Merck Oxifrit-Test to estimate polar compounds, the Merck Fritest to estimate carbonyl compounds (14), and the Policontrol Oil Test to estimate oxidized compounds are usually used for restaurant control. The aim of this restaurant simulation study was to compare the performance of soybean oil (SBO) and partially hydrogenated soybean oil (PHSBO) using physical and chemical methods, including some quick tests.

EXPERIMENTAL PROCEDURES

Materials. SBO and PHSBO were obtained from Cargill Agricola S.A. (São Paulo, Brazil). The potatoes (prefried with

*To whom correspondence should be addressed at USP, Prof. Lineu Prestes, São Paulo, Brazil. E-mail: sanibal@usp.br

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PHSBO and frozen) were supplied by Pratigel Ind. e Com. de Alimentos Ltda. (São Paulo, Brazil). The Fritest and Oxifrit-Test kits were obtained from Merck (Darmstadt, Germany), and the Oil Test was supplied by Policontrol (São Paulo, Brazil).

Methods. The oil-heating operation was conducted in a Fritanella-Walita® electric fryer with a capacity of 5 L. The fryer was heated to 180 ± 5°C. The SBO and PHSBO were heated for 10 h/d over 5 d, for a total of 50 h. The potatoes were fried for 4 min in each frying medium at a rate of 10% wt/vol SBO or PHSBO, totaling, at the end of 50 h of frying, 2310 g fried potatoes in SBO and 2310 g in PHSBO, corresponding to 46.2 g-h. At the end of a 10-h frying period, each oil sample was cooled and filtered; a 60-g sample was taken for test kits, and 240 g was kept at –18°C for further chemical and physical analyses. The volume was replenished daily with 10% vol/vol of fresh SBO or PHSBO.

Iodine value (IV). Determination of IV was conducted according to AOCS Official Method Cd 1d-92 (8). Oil (300 mg) was weighed and dissolved in 20 mL of cyclohexane/acetic acid (1:1). Wijs solution (25 mL) was added, and the reaction was carried out in the dark for 1 h. The reaction was stopped by adding sodium iodide solution. The remaining iodine was titrated using 0.1 N sodium thiosulfate solution, to confirm the FA analysis by GC.

Color index (CI). The photometric CI was determined according to Mancini-Filho *et al.* (12). The absorbance of melted oil samples was recorded at 420 nm with a UV-vis Hitachi spectrophotometer, Model U-3410.

FFA. FFA content as the percentage of oleic acid was determined using AOCS Official Method Ca5a-40 (8). Acid value was calculated by multiplying the percentage of FFA by 1.99 and was defined as the amount (mg) of KOH required to neutralize 1 g of oil sample.

TPC. Determination of polar compounds was conducted according to AOCS Official Method Cd 20-91 (8). Briefly, 2.5 g of oil was diluted in petroleum ether/diethyl ether (87:13, vol/vol) and made up to 50 mL with the same solvent mixture. Twenty milliliters of the solution was applied to a silica gel (Merck grade 60 mesh, water content standardized to 5%) column. The nonpolar fraction was eluted with 150 mL of petroleum ether/diethyl ether (87:13, vol/vol), and the polar fraction was eluted with 150 mL of diethyl ether. The fractions were weighed following evaporation of the solvent and drying.

FA. The FA profile analysis was performed by converting free and glyceride FA to their corresponding methyl esters (15) prior to the analysis by GC. Oil samples (50 mL) were methylated in 4 mL of 1 M methanolic KOH for 1 h at 23 ± 2°C. The resultant FAME were extracted with hexane and analyzed immediately on a model C17 Shimadzu gas chromatograph, using a fused-silica capillary column (100 m × 0.25 mm diameter; Model SP 2160, Supelco, Bellefonte, PA), an FID, and helium as the carrier gas (1 mL min^{-1}). The GC split ratio was 50:1. Initial column temperature was 170°C, holding 50 min, and then the instrument was programmed to 225°C at 4.0°C min^{-1} 30 min. Injector and FID temperatures were 275°C. FAME samples (1 mL) were injected by autosampler. FA were identified by chromatographic retention time by comparison with authentic standards (Sigma, St. Louis, MO) and by comparison with soybean oil chromatograms from Ratnayake *et al.* (16).

Test kits (Oxifrit-Test, Fritest, and Oil Test). After filtration, SBO and PHSBO samples were submitted to the following quick tests. The Oxifrit-Test, Fritest, and Oil Test use reagents that produce distinct colorations when the oil samples being tested contain oxidation products. The quality of the oil and fat can be evaluated immediately by comparison with the color scale.

Statistical analysis of data. Data from chemical and physical analyses and quick tests were evaluated statistically using ANOVA, the Tukey–Kramer test, and correlation coefficients (Microsoft Excel, v. 5.0; Microsoft Inc., Redmond, WA). The repetitions were done in triplicate.

RESULTS AND DISCUSSION

FA analysis. The FA profiles of the SBO and PHSBO are shown in Tables 1 and 2. The SBO and PHSBO had different proportions of saturated FA (SAFA), monounsaturated FA (MUFA), PUFA, monounsaturated *trans* FA (*trans* MUFA), and polyunsaturated *trans* FA (*trans* PUFA). The main differences were in 18:3n-3 and 18:2n-6; their contents were reduced 2.95 and 24.42%, respectively, when compared with the fresh SBO. PHSBO contained 28.9% *trans* FA (18:1) and had higher SAFA and lower PUFA than the SBO. SBO was rich in 18:2n-6, contained moderate amounts of 18:1n-9, but low amounts of 18:3n-3. The profile of all the major FA in SBO and PHSBO showed systematic changes during the course of deep-frying. The proportions of palmitic acid (16:0), stearic acid (18:0), and SAFA in the SBO and PHSBO increased significantly ($P < 0.001$). Linoleic (18:2n-6) and α-linolenic (18:3n-3) acids decreased significantly ($P < 0.001$) during frying. Changes in the oleic acid (18:1n-9) content during frying were not evident in SBO and PHSBO. The content of *trans* 18:1 in SBO and PHSBO increased significantly ($P < 0.001$) during deep-frying. The frying process has been considered to be a source of *trans* FA (4,17). The MUFA level in SBO and in PHSBO decreased significantly ($P < 0.05$) during frying.

The FA composition of an oil has marked effects on its frying performance as well as on its physical and chemical behavior. Nawar (9) related that during the course of deep-frying, the FA profile of the frying oils changed as a result of cyclization, polymerization, and pyrolitic, hydrolytic, oxidative, and other chemical reactions promoted by frying conditions. Changes in the FA profile during frying provide only limited information about these compositional changes, which are associated with oil degradation. On the other hand, the FA profile of the unused oil can be used to predict its subsequent performance and stability during frying. A previous study showed that reducing the content of α-linolenic acid in vegetable oils increased oxidative stability of the oils (18). The present study demonstrates in addition that the content of 18:3n-3 and 18:2n-6 is critical to the frying performance and stability of the oils and to the flavor as well as to the overall quality of the fried food. Linoleic

TABLE 1
Soybean Oil FA Compounds at Several Frying Times[a]

FA	0 h	10 h	20 h	30 h	40 h	50 h
			Average (%)			
14:0	0.07 ± 0.00	0.07 ± 0.01	0.08 ± 0.00	0.09 ± 0.00	0.09 ± 0.01	0.10 ± 0.00
16:0	10.84 ± 0.09	11.38 ± 0.09	11.62 ± 0.05	12.23 ± 0.03	12.53 ± 0.05	12.37 ± 0.07
16:1	0.07 ± 0.01	0.06 ± 0.01	0.06 ± 0.01	0.07 ± 0.01	0.06 ± 0.01	0.06 ± 0.00
17:0	0.08 ± 0.01	0.08 ± 0.01	0.08 ± 0.01	0.09 ± 0.00	0.10 ± 0.00	0.10 ± 0.00
18:0	3.32 ± 0.02	4.86 ± 0.05	6.15 ± 0.02	7.52 ± 0.04	8.77 ± 0.11	9.61 ± 0.10
18:1 9*t*	0.00 ± 0.00	0.76 ± 0.03	1.32 ± 0.08	1.78 ± 0.03	2.45 ± 0.39	2.84 ± 0.30
18:1 *trans*	0.00 ± 0.00	1.55 ± 0.72	5.03 ± 0.14	7.33 ± 0.20	9.54 ± 0.37	11.43 ± 0.47
18:1 9*c*	21.25 ± 0.08	21.83 ± 0.18	21.98 ± 0.16	22.57 ± 0.19	22.62 ± 0.12	22.22 ± 0.10
18:1 10*c*	1.37 ± 0.01	1.50 ± 0.01	1.60 ± 0.00	1.72 ± 0.01	1.82 ± 0.02	1.87 ± 0.01
18:1 11*c*	—	0.37 ± 0.03	0.72 ± 0.00	1.05 ± 0.01	1.33 ± 0.01	1.47 ± 0.01
18:1 12*c*	—	0.13 ± 0.00	0.20 ± 0.01	0.26 ± 0.00	0.33 ± 0.00	0.39 ± 0.00
18:1 13*c*	—	—	0.19 ± 0.01	0.28 ± 0.01	0.38 ± 0.01	0.47 ± 0.00
18:2 9*t*,12*c*/9*c*,12*t*	—	—	0.09 ± 0.00	0.12 ± 0.00	0.14 ± 0.01	0.15 ± 0.01
18:2 9*t*,12*t*	—	—	0.16 ± 0.00	0.24 ± 0.01	0.30 ± 0.01	0.34 ± 0.00
18:2 9*c*,12*t*	0.57 ± 0.01	0.81 ± 0.01	0.66 ± 0.25	0.78 ± 0.00	0.77 ± 0.01	0.74 ± 0.02
18:2 9*t*,12*c*	0.15 ± 0.03	0.77 ± 0.01	0.65 ± 0.19	0.39 ± 0.04	0.70 ± 0.01	0.67 ± 0.01
18:2 9*c*,12*c*	55.11 ± 0.05	49.36 ± 0.37	43.65 ± 0.20	38.08 ± 0.02	33.56 ± 0.14	30.69 ± 0.18
20:0	0.35 ± 0.01	0.37 ± 0.01	0.38 ± 0.00	0.41 ± 0.00	0.43 ± 0.01	0.42 ± 0.00
18:3 *trans*	1.38 ± 0.03	1.68 ± 0.01	1.52 ± 0.01	1.24 ± 0.01	1.06 ± 0.00	0.95 ± 0.01
18:3 9*c*,12*c*,15*c*	4.79 ± 0.01	3.59 ± 0.03	2.96 ± 0.01	2.37 ± 0.01	1.98 ± 0.01	1.84 ± 0.02
22:0	0.43 ± 0.01	0.46 ± 0.00	0.47 ± 0.00	0.50 ± 0.01	0.51 ± 0.01	0.50 ± 0.01
24:0	0.15 ± 0.01	0.15 ± 0.01	0.16 ± 0.00	0.17 ± 0.00	0.16 ± 0.01	0.16 ± 0.01
Not identified	0.07	0.22	0.27	0.71	0.37	0.61
SAFA	15.24^{f}	17.38^{e}	18.94^{d}	21.01^{c}	22.59^{b}	23.26^{a}
MUFA	22.69^{e}	23.89^{d}	24.75^{c}	25.95^{b}	26.67^{a}	26.64^{a}
PUFA	59.90^{a}	52.95b	46.61^{c}	40.45d	35.54e	32.58^{f}
Trans MUFA	0.00^{f}	2.10^{e}	6.35^{d}	9.11^{c}	11.99^{b}	14.27^{a}
Trans PUFA	2.10^{e}	3.26^{a}	3.08^{b}	3.11^{a}	2.97^{c}	2.85^{d}

[a]Values (mean ± SD) in the same row with different superscript letters are significantly different ($P < 0.05$). The FA profile was obtained by comparison with chromatograms of Ratnayake *et al.* (15) and standards. SAFA, saturated FA; MUFA, monounsaturated FA.

acid (18:2n-6) was the major PUFA in these frying media. Its relative amount decreased significantly during frying. The linoleic acid level in deep-frying oils appears to be an obviously negative factor in oil stability. Indeed, previous studies indicated that a lowered linoleic acid content in soybean oil (achieved through plant breeding) resulted in improved oil quality during cooking and frying (19). In this study, SBO had a higher linoleic level (55.1%) than PHSBO (11.9%). PHSBO was more stable chemically and physically. All FA presented in Tables 1 and 2 were determined with some standards and the chromatographic profile presented by Ratnayake *et al.* (15).

Determination of IV. SBO had a higher initial IV (121.7) due to its higher PUFA content. PHSBO had an IV of 85.6 (Tables 3 and 4). The IV of the SBO and PHSBO decreased significantly during the course of frying ($P < 0.001$). During heat treatment, a progressive decrease in unsaturation in SBO and PHSBO was observed, as evidenced by measurement of IV. This decrease can be attributed to a reduction in the unsaturated FA content (20). Similar to the production of TPC, SBO had the greatest loss of unsaturation after 30 h of frying (Table 3). The more-saturated PHSBO had slower changes in unsaturation than SBO (Table 4).

Determination of CI. The color of SBO and PHSBO increased significantly ($P < 0.001$) during deep-frying. The color of both SBO and PHSBO changed from clear pale yellow to light brown and then dark brown during deep-frying. In comparing the color-darkening patterns in the SBO and PHSBO (Tables 3 and 4), it is apparent that color is not a reliable indicator of oil quality. The results support the assessment of Blumenthal (21) that oil color should not be used as a primary index for oil quality or for discard time.

Test kits. The Oxifrit-Test, Fritest, and Oil Test provide a fast and convenient way to monitor oil quality. The SBO and PHSBO had similar results initially, but significant differences ($P < 0.05$) developed during the course of frying. SBO had the earlier discard point in the Oxifrit-Test and Fritest (Table 5). This may have been due to differences in α-linolenic and linoleic acid contents or possibly in some other minor components in the SBO and PHSBO, such as different levels and types of antioxidants and antifoaming agents. The test kit results and TPC of the SBO and PHSBO in this study were significantly correlated (Tables 6 and 7). In this case, the highest TPC content was detected in SBO during deep-frying. This suggests that TPC contribute significantly to the test kit results, but probably are only one factor affecting quick tests.

FFA. FFA are formed during oxidation, hydrolysis, and pyrolysis as a result of the cleavage of TAG (22). Previous studies of frying oils have shown that the FFA content increases during deep-frying (23). The SBO and PHSBO had similar FFA levels during frying, although initially the content was slightly higher

TABLE 2
Partially Hydrogenated Soybean Oil FA Compounds at Several Frying Times

FA	0 h	10 h	20 h	30 h	40 h	50 h
			Average (%)			
14:0	0.19 ± 0.01	0.19 ± 0.01	0.18 ± 0.00	0.17 ± 0.00	0.18 ± 0.01	0.18 ± 0.02
16:0	13.37 ± 0.02	13.33 ± 0.02	13.25 ± 0.03	13.24 ± 0.02	13.27 ± 0.07	13.11 ± 0.17
16:1	0.11 ± 0.00	0.10 ± 0.00	0.10 ± 0.01	0.09 ± 0.00	0.08 ± 0.01	0.08 ± 0.02
17:0	0.08 ± 0.01	0.09 ± 0.01	0.09 ± 0.00	0.09 ± 0.00	0.10 ± 0.01	0.10 ± 0.01
18:0	7.34 ± 0.05	8.53 ± 0.01	9.44 ± 0.04	9.50 ± 1.21	10.86 ± 0.03	11.17 ± 0.33
18:1 9*t*	8.31 ± 0.97	9.58 ± 0.27	10.63 ± 0.66	11.18 ± 0.12	11.66 ± 0.16	12.37 ± 1.15
18:1 *trans*	11.91 ± 1.96	14.02 ± 0.20	14.30 ± 0.73	15.88 ± 1.48	15.46 ± 0.26	15.64 ± 1.19
18:1 9*c*	26.82 ± 1.53	24.64 ± 0.03	24.29 ± 0.06	23.81 ± 0.46	23.59 ± 0.11	23.67 ± 0.48
18:1 10*c*	1.92 ± 0.03	2.02 ± 0.00	2.05 ± 0.02	2.09 ± 0.03	2.13 ± 0.01	2.20 ± 0.00
18:1 11*c*	6.07 ± 0.00	5.88 ± 0.01	5.76 ± 0.03	5.66 ± 0.03	5.51 ± 0.03	5.41 ± 0.05
18:1 12*c*	0.31 ± 0.00	0.37 ± 0.00	0.42 ± 0.00	0.46 ± 0.01	0.49 ± 0.00	0.52 ± 0.01
18:1 13*c*	0.36 ± 0.00	0.44 ± 0.02	0.51 ± 0.01	0.55 ± 0.01	0.60 ± 0.01	0.62 ± 0.02
18:1 14*c*	0.20 ± 0.00	0.20 ± 0.00	0.20 ± 0.00	0.20 ± 0.01	0.21 ± 0.01	0.21 ± 0.02
18:1 15*c*	0.22 ± 0.01	0.26 ± 0.01	0.27 ± 0.01	0.29 ± 0.00	0.29 ± 0.01	0.31 ± 0.01
18:2 9*t*,12*c*/9*c*,12*t*	0.80 ± 0.01	0.72 ± 0.01	0.67 ± 0.01	0.62 ± 0.00	0.59 ± 0.00	0.57 ± 0.00
18:2 9*t*,12*t*	1.78 ± 0.01	1.68 ± 0.01	1.61 ± 0.01	1.54 ± 0.01	1.50 ± 0.01	1.46 ± 0.01
18:2 9*c*,12*t*	2.71 ± 0.02	2.43 ± 0.00	2.20 ± 0.01	1.99 ± 0.01	1.84 ± 0.01	1.69 ± 0.03
18:2 9*t*,12*c*	2.43 ± 0.07	2.11 ± 0.02	1.89 ± 0.04	1.74 ± 0.07	1.55 ± 0.02	1.43 ± 0.03
18:2 *trans*	0.84 ± 0.04	0.91 ± 0.01	0.84 ± 0.09	0.74 ± 0.01	0.74 ± 0.02	0.74 ± 0.02
18:2 9*c*,12*c*	11.89 ± 0.01	10.43 ± 0.02	9.27 ± 0.04	8.23 ± 0.05	7.40 ± 0.06	6.72 ± 0.03
18:2 9*c*,15*c*	0.45 ± 0.02	0.43 ± 0.01	0.39 ± 0.01	0.37 ± 0.01	0.36 ± 0.00	0.34 ± 0.02
20:0	0.37 ± 0.01	0.38 ± 0.00	0.39 ± 0.00	0.40 ± 0.00	0.41 ± 0.00	0.40 ± 0.01
18:3 *trans*	0.14 ± 0.02	0.11 ± 0.01	0.08 ± 0.03	0.05 ± 0.00	—	—
18:3 9*c*,12*c*,15*c*	0.42 ± 0.00	0.37 ± 0.03	0.30 ± 0.01	0.27 ± 0.01	0.30 ± 0.08	0.24 ± 0.01
22:0	0.40 ± 0.00	0.41 ± 0.00	0.42 ± 0.01	0.43 ± 0.00	0.44 ± 0.00	0.44 ± 0.02
24:0	0.14 ± 0.00	0.14 ± 0.01	0.14 ± 0.00	0.15 ± 0.00	0.15 ± 0.00	0.15 ± 0.00
Not identified	0.42	0.23	0.31	0.26	0.29	0.23
SAFA	21.89^{d}	23.07^{c,d}	23.91^{c}	23.98^{b,c}	25.41^{a,b}	25.55^{a}
MUFA	36.01^{a}	33.91^{b}	33.60^{b}	33.15^{b}	32.90^{b}	33.02^{b}
PUFA	12.76^{a}	11.23^{b}	9.96^{c}	8.87^{d}	8.06^{e}	7.30^{f}
Trans MUFA	20.22^{d}	23.60^{b}	24.93^{b,c}	27.06^{a,c}	27.12^{a,c}	28.01^{a}
Trans PUFA	8.70^{a}	7.96^{b}	7.29^{c}	6.68^{d}	6.22^{e}	5.89^{f}

[a]Values (mean ± SD) in the same row with different superscript letters are significantly different ($P < 0.05$). The FA profile was obtained by comparison with the chromatograms of Ratnayake *et al.* (15) and standards. For abbreviations see Table 1.

in the SBO. FFA contents of the SBO and PHSBO increased significantly during frying (Tables 3 and 4) and were strongly correlated with IV, TPC, linoleic acid, α-linolenic acid, and the quick tests (Oxifrit-Test, Fritest, and Oil Test) (Tables 6 and 7). Although the changes in FFA were highly correlated with these analytical parameters during frying in this study, it is not recommended to use FFA as the only indicator to determine the life of frying oil. In practice, FFA levels may not affect frying performance or have significant adverse effects on health or sensory evaluation of the product fried (24). For example, in this study SBO and PHSBO had similar FFA levels during frying (Tables 3 and 4).

TABLE 3
Soybean Oil Analytical Parameters at Several Frying Times[a]

	0 h	30 h	50 h
FFA content (% oleic acid)	0.3 ± 0.0^{c}	0.6 ± 0.1^{b}	0.9 ± 0.0^{a}
Color index	0.1 ± 0.0^{c}	1.5 ± 0.0^{b}	2.0 ± 0.0^{a}
IV	121.7 ± 4.2^{b}	101.5 ± 0.3^{a}	92.6 ± 0.3^{c}
TPC	8.6 ± 0.2^{c}	28.3 ± 0.9^{b}	40.5 ± 8.0^{a}
SAFA	15.2^{c}	21.0^{b}	23.3^{a}
MUFA	22.7^{c}	26.0^{b}	26.6^{a}
PUFA	59.9^{a}	40.5^{b}	32.6^{c}
Trans MUFA	0.0^{c}	9.1^{b}	14.3^{a}
Trans PUFA	2.1^{c}	3.1^{a}	2.9^{b}

[a]Values (mean ± SD) in the same row with different superscript letters are significantly different ($P < 0.05$). IV, iodine value; TPC, total polar compounds; for other abbreviations see Table 1.

TABLE 4
Partially Hydrogenated Soybean Oil Analytical Parameters at Several Frying Times[a]

	0 h	30 h	50 h
FFA content (% oleic acid)	0.1 ± 0.0^{c}	0.7 ± 0.0^{b}	1.0 ± 0.1^{a}
Color index	0.2 ± 0.0^{c}	0.9 ± 0.0	2.2 ± 0.0^{a}
IV	85.6 ± 0.2^{a}	77.1 ± 0.5^{b,d}	77.0 ± 0.4^{c,d}
TPC	6.6 ± 0.3^{c}	18.0 ± 0.6^{b}	23.0 ± 2.3^{a}
SAFA	21.9^{c}	24.0^{b}	25.6^{a}
MUFA	36.0^{a}	33.2^{b}	33.0^{b}
PUFA	12.8^{a}	8.9^{b}	7.3^{c}
Trans MUFA	20.2^{b}	27.1^{a}	28.0^{a}
Trans PUFA	8.7^{a}	6.7^{b}	5.9^{c}

[a]Values (mean ± SD) in the same row with different superscript letters are significantly different ($P < 0.05$). For abbreviations see Tables 1 and 3.

TABLE 5
Quick Tests of Soybean Oil (SBO) and Partially Hydrogenated Soybean Oil (PHSBO) at Each 10-h Frying Time

	Oxifrit-Test		Fritest		Oil Test	
Hours	SBO	PHSBO	SBO	PHSBO	SBO	PHSBO
10	Good	Good	Good	Good	Good	Good
20	Still good	Good	Still good	Still good	Regular	Regular
30	Still good	Good	Change	Change	Change	Change
40	Change	Still good	Bad	Change	Change	Change
50	Change	Change	Bad	Bad	Change	Change

TABLE 6
Correlation Coefficient Between Different Analytical Parameters of SBO[a]

	A	B	C	D	E	F	G	H	I
A	1.00	—	—	—	—	—	—	—	—
B	0.98	1.00	—	—	—	—	—	—	—
C	–0.96	–0.99	1.00	—	—	—	—	—	—
D	–0.96	–0.99	0.99	1.00	—	—	—	—	—
E	–0.92	–0.97	0.99	—	1.00	—	—	—	—
F	–0.99	–0.99	–0.97	0.97	0.93	0.42	1.00	—	—
G	–0.97	–0.99	0.99	0.99	0.93	–0.58	—	1.00	—
H	–0.84	–0.92	0.95	0.95	0.98	–0.81	—	—	1.00

[a]A, FFA (% oleic acid); B, TPC; C, IV; D, linoleic acid; E, linolenic acid; F, Oxifrit-test; G, Fritest; H, Oil test. Correlation coefficients having absolute values ≥ 80% are significant at a level of $P > 0.05$. For abbreviations see Tables 3 and 5.

TABLE 7
Correlation Coefficient Between Different Analytical Parameters of PHSBO[a]

	A	B	C	D	E	F	G	H	I
A	1.00	—	—	—	—	—	—	—	—
B	0.99	1.00	—	—	—	—	—	—	—
C	–0.92	–0.95	1.00	—	—	—	—	—	—
D	–0.99	–0.99	0.96	1.00	—	—	—	—	—
E	–0.96	–0.98	0.98	—	1.00	—	—	—	—
F	–0.87	–0.73	0.50	0.72	0.62	–0.40	1.00	—	—
G	–0.99	–0.99	0.94	0.93	0.98	–0.90	—	1.00	—
H	–0.99	–0.99	0.99	0.99	0.99	–0.91	—	—	1.00

[a]Correlation coefficients having absolute values ≥ 80% are significant at a level of $P > 0.05$. For abbreviations see Table 6.

Determination of TPC. TPC in SBO and PHSBO increased significantly during frying (Tables 1 and 2). TPC contents of unused SBO and PHSBO initially were similar. The increase in rate of TPC formation in the SBO was different from PHSBO. After 50 h of frying, the final TPC levels were 40.5% in SBO and 23.0% in PHSBO (Tables 3 and 4). TPC in frying oil are composed of breakdown products, nonvolatile oxidized derivatives, polymeric and cyclic substances produced in the course of deep-frying microparticulates, and soluble components from the food fried in this oil. The TPC content of frying oil has been proposed as a good indicator of frying oil quality, with high correlation coefficients with the other parameters in Table 6. Several countries have suggested that oil with 25–27% TPC should be discarded (1), and other countries have even adopted this as a regulatory parameter (13). If the maximal content for TPC in frying oil is accepted as 25%, the TPC-based stability is 30 h of frying for SBO and 50 h for PHSBO. TPC contents were strongly correlated with IV, TPC, linoleic acid, α-linolenic acid, and the Oxifrit-Test, Fritest, and Oil Test (Tables 6 and 7).

The results of this work show that the frying of potatoes in SBO and PHSBO can be monitored by the Oxifrit-Test, Fritest, and Oil Test.

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