Survey of Quality of Used Frying Oils from Restaurants

Hassan A. Al-Kahtani*
Department of Food Science, King Saud University, Riyadh 11451, Saudi Arabia

Commercial frying practices and frying conditions at 62 restaurants or fast-food outlets were investigated and the quality of their discarded frying oils was evaluated by several standard laboratory methods: total polar components (TPC), free fatty acids (%FFA), p-anisidine and peroxide values, color, viscosity, C18:2/C16:0, absorbance at 232 and 268 nm, and five quick test methods (Foodoil sensor, Oxifrit (RAU-Test), Fritest, Veri-Fry-TAM 150, and Veri-Fry-FFA 500). Frying techniques varied from primitive traditional practice at traditional shops to modern sophisticated frying procedures at some franchise restaurants. Discarded oils appeared to be heat-damaged to a varying extent according to the degree of quality control applied by the corresponding restaurants. Test methods were shown to possess different statistical correlations. Highly significant correlations were found between TPC and Foodoil sensor (c.f = 0.93) and between Oxifrit and Fritest (c.f = 0.94), each of which were also correlated relatively well to the TPC. Peroxide value followed by %FFA did not significantly ($p<0.05$) correlate with the TPC. Significant linear relationships ($p \oplus 0.05$) were found between the TPC and each of the other indicators but %FFA and peroxide value.

KEY WORDS: **Broast shops, discarded frying oils, foodoil sensor, franchise companies, fritest, Oxifrit (RAU-Test), total polar components, traditional shops, Veri-Fry-FFA-500, Veri-Fry-TAM-150.**

Fat or oil frying is a method of cooking commonly used for the manufacture and preparation of foods. The fat serves as a heat-transfer medium and as an important ingredient of the fried food. It is repeatedly or continuously used at elevated temperatures, and various chemical processes (hydrolysis, polymerization, oxidation and fission) take place (1). This results in the accumulation of decomposition products that not only affect the quality of fried foods but also are of much concern to human health, particularly when frying fat or oil is highly abused (2–7). Numerous methods have been described for the measurement of fat or oil deterioration (1,8).

Most of the published work on frying practices or frying oil deterioration has been carried out under carefully controlled laboratory conditions, which can be different from those encountered in actual practice at restaurants or fast-food outlets. The extent and nature of decomposition products are affected by some frying parameters such as fat and food composition, frying conditions (temperature, oxygen exposure, heating time, turnover rate), and design and material of frying equipment (9) which differ from one place to another. In Saudi Arabia, so far no attempt has been made to carry out such investigations; therefore, this comprehensive study was conducted to identify the fat-frying practices applied commercially by some local restaurants or franchise companies in Riyadh, and to evaluate the quality of their discarded frying oils by standard laboratory methods and quick-test methods. Statistical comparative investigations among these methods were also carried out.

MATERIALS AND METHODS

Materials. Sixty-two restaurants, randomly chosen from different locations in Riyadh, Saudi Arabia, were visited and some frying parameters (oil, food, fryer, and frying conditions) were reported at each restaurant. Information on frying cycles and exact oil turnover rates could not be obtained. The chosen restaurants (50 individual-owned restaurants and 12 franchise restaurants) represented all possible techniques of fat frying in the country. Each operator was left with a one-liter clean glass bottle and was asked to save a sample when he was about to discard the frying oil according to his normal practice. The corresponding fresh frying oils were also collected. Oil samples were filtered, blanketed with nitrogen gas and stored in the cold (−20°C) before analysis.

Methods. Standard laboratory methods. The content of total polar components (TPC) was determined by column chromatography according to Billek *et al.* (10). Determinations of peroxide value (11), and free fatty acids (FFA) and p-anisidine (12) were also carried out. The conjugated diene and triene contents were determined by spectrophotometer (Beckman Model 35, Fullerton, CA) at 232 nm and 268 nm, respectively (13–15). The viscosity (Brookfield viscometer, Stoughton, MA) (16,17) and color (Lovibond Tintometer, Model E, Salisbury, England) of the oils were measured (14).

Fatty acid profiles of the oils were determined by gas chromatography (18). The fatty acid methyl esters were identified on a 5840 A gas chromatograph (Hewlett-Packard, Palo, Alto, CA) with a flame ionization detector and a 190 × 0.2 cm column packed with 70% DEGS on 100/120 high performance chromosorb W. The C18:2/C16:0 ratio was calculated from the fatty acid composition.

Quick-test methods. Foodoil sensor (N1-21A, Northern Instrument Corp., Lino Lakes, MN) was used to measure the dielectric constant in discarded frying oils relative to fresh oils (15,19). Four colorimetric diagnostic test kits (Fritest, Oxifrit or RAU-Test, Veri-Fry-FFA 500, and Veri-Fry-TAM 150) were used for visual evaluation of discarded frying oil quality. Fritest and Oxifrit (products of Merck, Darmstadt, Germany) are sensitive to carbonyl compounds and oxidized compounds, respectively (20). Both kits have a color scale consisting of four diagnostic colors; "Good," "Still Good," "Replace" and "Bad," which were set to 1,2,3, and 4, respectively, or in steps of 0.5 for statistical calculations. The Veri-Fry-FFA 500 and Veri-Fry-TAM 150 kits are products of Libra laboratories Inc., Piscataway, NJ. The former is for the measurement of free fatty acids and the latter was for the estimation of total alkaline materials (soap concentration, ppm) in discarded frying oils (21). The color scale of these two kits consists of five diagnostic colors, each of which corresponds to a range of values for free fatty acids (%) or for total alkaline materials (ppm). The color was read in steps of 0.5 in a range from 1 to 5 for the data analysis.

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*To whom correspondence should be addressed at Department of Food Science, King Saud University, P.O. Box 2460, Riyadh 11451, Saudi Arabia.

Statistical analysis. The relationships between each of the standard laboratory methods and each of the quick-test methods were determined (22,23). Equations of regression lines between TPC and each of the other methods were established.

RESULTS AND DISCUSSION

Fatty acid compositions of starting (fresh) oils. The fatty acid compositions of fresh oils are reported in Table 1. The unhydrogenated palm oil (PO) with added vitamins (A and D), a product of Saudi Vegetable Oil and Ghee Company, Jeddah, Saudi Arabia, the most widely used frying oil in the country, contained 41.5% C18:1 and 11.7% C18:2. The percentages of C18:1, C18:2, and C18:3 in partially hydrogenated soybean oil and cottonseed oil with no additives (premium vegetable oil for food deep-fat frying, Red Label, Kraft Co., Rocky Mountain, CO) were 58.6, 2.8, and 0.4%, respectively. In hydrogenated vegetable oil (HVO), vegetable shortening of Colfex Incorporated, Boston, MA, (name of the oil was not included in the label) with no additives, the C18:1, C18:2, and C18:3 were 55.6, 2.9, and 1.5%, respectively.

Frying practices. The frying practices applied by different restaurants varied in terms of oil and food types, fryer selection (kettle design, material of fabrication, capacity, and ease of cleaning), frying conditions (temperature and total frying time), and quality control during frying (Table 2 and Table 3). The traditional shops used primitive frying techniques and an open conventional gas-fried steel pan (45 cm in diameter, and an oil depth of 8 cm), which did not meet any of the frying operation requirements. In contrast, franchise companies, particularly company A, utilized the latest modern frying technique with computer assistance for better quality control. Individual traditional shops and broast shops varied widely in length and conditions of usage while variations among franchise companies' branches were minimum. Therefore, the extent and nature of oil degradation during frying would be different (9).

Standard laboratory methods. The quality of discarded frying oils and their corresponding fresh oils were evaluated by several physical and chemical procedures, and the analytical data are given in Table 2 and Table 3. The total polar components (TPC) for discarded frying oils represented all oxidation and decomposition products formed during frying, and the size of the polar fraction indicated the degree of deterioration (3). The results

TABLE 1

Fatty Acid Composition of Fresh Frying Oils[a]

Fatty acid	Palm oil (PO)	Partially hydrogenated soybean oil and cottonseed oil (PHSOCO)	Hydrogenated vegetable oil (HVO)
12:0	2.80 ± 0.06	4.69 ± 0.08	—
14:0	1.95 ± 0.09	1.47 ± 0.10	1.93 ± 0.25
16:0	34.65 ± 0.14	12.04 ± 0.63	12.18 ± 0.15
18:0	5.15 ± 0.07	16.10 ± 0.41	23.82 ± 0.65
18:1	41.45 ± 0.42	58.55 ± 0.93	55.58 ± 0.95
18:2	11.65 ± 0.21	2.75 ± 0.20	2.86 ± 0.42
20:0	0.60 ± 0.02	0.62 ± 0.01	1.22 ± 0.35
18:3	—	0.38 ± 0.05	1.48 ± 0.70
Others	1.75 ± 0.35	3.40 ± 0.95	0.93 ± 0.43

[a] Analyses are average of duplicate determinations.

TABLE 2

Frying Practices of Discarded Frying Oils

	Oil		Frying conditions				
Restaurant	Type[a]	Usage[b]	Temp. (°F)	Hr/D	Days	Fryer[c]	No.
Individual traditional shops	PO	fresh	—	—	—	—	1
		fish	353	8	3	A	2
		fish	340	9	2	A	3
		fish	340	5	2	A	4
		chicken	354	8	2	A	5
		chicken	360	6	3	A	6
		potatoes	346	3	2	A	7
		potatoes	329	6	3	A	8
		potatoes	350	8	3	A	9
		fallafel	343	8	3	A	10
		fallafel	327	5	3	A	11
		fallafel	355	9	4	A	12
		fallafel	332	4	3	A	13
		fallafel	345	3	2	A	14
		fallafel	350	3	2	A	15
		fallafel	350	9	4	A	16
		sanbosak	318	7	2	A	17
		sanbosak	325	4	2	A	18
		sanbosak	350	4	3	A	19
		sanbosak	350	5	2	A	20
		mixed	336	8	2	A	21
		mixed	321	5	2	A	22
		mixed	350	7	3	A	23
		mixed	355	8	4	A	24
		mixed	350	6	3	A	25
		mixed	360	5	3	A	26
Individual broast shops	PO	fish	350	10	3	B	27
		fish	350	8	3	B	28
		fish	360	12	5	C	29
		fish	360	10	4	B	30
		fish	355	12	4	B	31
		fish	345	7	5	C	32
		chicken	325	14	3	B	33
		chicken	350	13	3	B	34
		chicken	355	10	3	C	35
		chicken	360	11	3	C	36
		chicken	350	8	4	B	37
		potatoes	338	6	3	B	38
		potatoes	350	12	4	B	39
		potatoes	340	8	2	B	40
		potatoes	335	12	3	C	41
		mixed	360	12	3	B	42
		mixed	345	12	3	C	43
		mixed	350	7	3	C	44
		mixed	325	12	3	B	45
		mixed	300	7	4	B	46
		mixed	350	8	3	C	47
		mixed	340	10	5	B	48
		mixed	360	12	3	B	49
		mixed	375	10	4	C	50
		mixed	345	12	3	B	51
Company A (4 branches)	PHSOCO	fresh	—	—	—	—	52
		french fries	350	16	2	D	53
		Hardees' products	350	16	5	D	54
Company B (6 branches)	PHSOCO	french fries	350	16	5	E	55
		Kentucky Fried Chickens' products	365	16	4	F	56
Company C (2 branches)	HVO	fresh	—	—	—	—	57
		doughnuts	375	8	7	G	58

[a] PO = palm oil; PHSOCO = partially hydrogenated soybean oil and cottonseed oil; HVO = hydrogenated vegetable oil.

[b] Potatoes = fresh sliced potatoes; fallafel = middle eastern vegetable patties; sanbosak = meat and vegetable mixture stuffed patties; Hardees' products = chicken, fish and meat; mixed = mixture of foods including the above items.

[c] A = conventional gas-fried steel pan; B = 500 psi pressure fryer (Henny Penny Corp., Easton, OH); C = electric broaster model 1800E (Broco Products Co., Beloit, WI); D = Frymaster, model FM 345 EUMSD (Food Service Equipment & Supplies, Rocky Mount, NC); E = Fryer of Henny Penny Corp. exclusively used in the Kentucky Fried Chicken; F = Fryer of Keating of Chicago, Inc., IL; G = Picto Frialator (Markure, CA).

TABLE 3

Frying Characteristics of Discarded Frying Oils

	Oil characteristics[a]					Absorbance		Viscosity	Color	
No.	TPC (%)	FFA (%)	p-anisidine	PV	C18:2/C16:0	232	268		Red	Yellow
1	3.60 ± 0.4	0.2 ± 0.06	4.3 ± 0.49	3.2 ± 0.21	0.34 ± 0.01	0.44 ± 0.07	0.02 ± 0.01	48.0 ± 4.3	3.3 ± 0.4	28.3 ± 2.4
2	19.7	0.49	58.3	8.9	0.28	2.07	0.58	76.0	14.0	72.0
3	16.6	0.45	32.8	3.5	0.29	1.81	0.41	66.7	21.0	68.0
4	6.7	0.30	38.4	5.9	0.39	0.79	0.30	57.4	7.8	50.0
5	12.3	1.51	58.9	10.2	0.45	1.12	0.33	84.0	40.0	9.8
6	14.8	0.87	48.9	18.1	0.28	1.30	0.37	75.8	25.2	9.5
7	5.5	0.30	14.5	13.2	0.31	0.94	0.28	65.2	3.1	69.1
8	16.3	0.60	36.6	3.8	0.29	1.51	0.32	64.0	5.0	60.2
9	14.2	0.47	56.9	3.9	0.26	2.12	0.40	79.0	1.3	10.0
10	17.2	0.65	57.5	3.6	0.25	2.02	0.44	78.9	20.0	70.0
11	9.2	0.45	27.2	6.4	0.31	0.62	0.42	72.0	18.3	79.7
12	28.0	1.88	92.9	10.0	0.20	2.12	0.55	127.0	9.3	10.5
13	11.3	0.49	63.2	9.9	0.29	1.50	0.39	76.6	5.0	16.0
14	5.7	0.40	31.8	20.5	0.25	1.47	0.34	50.8	9.1	70.9
15	6.0	0.30	32.2	10.0	0.32	0.67	0.30	56.0	12.1	60.0
16	33.1	1.20	147.6	16.8	0.17	2.67	0.57	105.0	4.9	30.0
17	13.7	0.35	76.5	17.5	0.30	1.72	0.38	87.0	6.7	73.0
18	5.5	0.21	37.5	16.5	0.32	1.02	0.19	71.5	1.1	58.0
19	11.8	0.20	66.5	24.1	0.31	1.99	0.64	82.0	1.5	52.4
20	10.0	0.30	27.3	26.5	0.27	2.07	0.38	92.0	1.4	61.7
21	6.2	0.17	31.2	15.7	0.60	1.12	0.30	75.0	1.1	51.0
22	5.6	0.30	41.6	8.2	0.29	1.30	0.31	77.0	5.1	50.0
23	14.2	0.51	90.0	38.0	0.24	2.12	0.44	71.2	1.3	18.0
24	25.3	1.45	84.1	14.1	0.19	2.35	0.46	89.0	8.1	60.0
25	14.1	0.81	71.3	18.7	0.23	1.83	0.46	59.0	20.0	18.0
26	15.0	0.32	62.9	28.7	0.21	2.00	0.48	85.8	21.5	15.5
27	5.2	0.60	21.6	4.0	0.41	1.18	0.79	57.0	9.8	20.0
28	5.4	0.25	23.8	6.6	0.43	0.92	0.29	65.0	4.7	38.0
29	23.9	1.41	90.3	5.6	0.40	2.42	0.53	83.5	30.9	79.8
30	15.3	4.10	68.7	13.9	0.38	1.10	0.51	58.3	28.1	19.7
31	13.9	2.10	54.1	15.0	0.42	0.95	0.42	70.1	35.0	8.8
32	13.5	1.30	55.0	12.8	0.42	1.21	0.39	61.1	27.3	28.0
33	7.8	0.53	39.7	4.2	0.33	0.89	0.36	76.0	3.1	19.0
34	14.1	3.10	30.3	3.2	0.34	1.67	0.46	72.0	25.8	59.9
35	13.1	0.70	45.1	6.4	0.32	1.70	0.37	95.0	8.3	47.0
36	15.6	5.60	30.2	2.9	0.38	1.38	0.38	55.0	34.0	78.1
37	18.3	4.20	50.8	14.6	0.40	1.78	0.55	115.0	41.8	15.0
38	5.9	1.25	17.2	10.6	0.32	0.51	0.21	44.8	4.1	19.9
39	20.1	6.15	93.4	9.5	0.28	1.03	0.40	104.0	44.9	40.0
40	5.9	1.81	24.0	5.2	0.31	0.77	0.25	48.1	5.0	45.0
41	15.1	5.10	39.4	6.8	0.35	1.27	0.35	52.0	9.1	23.7
42	17.4	1.40	69.6	3.5	0.42	1.09	0.43	78.1	14.6	18.9
43	16.1	1.10	54.3	23.8	0.62	1.29	0.35	58.9	22.3	9.0
44	4.3	0.23	40.4	8.9	0.28	1.10	0.34	71.4	13.0	27.0
45	7.8	0.17	16.8	5.3	0.27	0.84	0.21	70.0	11.9	20.0
46	6.3	1.05	18.5	5.5	0.35	0.65	0.27	72.0	7.3	48.0
47	6.1	0.95	27.2	4.6	0.39	0.58	0.23	68.0	10.0	38.0
48	20.6	2.9	77.3	15.2	0.20	0.96	0.30	110.0	9.3	51.4
49	19.5	4.1	91.5	18.1	0.21	1.35	0.39	85.1	38.7	10.1
50	22.1	6.5	75.7	20.2	0.26	2.00	0.41	80.9	30.2	11.9
51	13.7	2.8	46.3	9.7	0.41	1.10	0.38	62.0	19.7	9.0
52	0.99 ± 0.2	0.26 ± 0.09	3.6 ± 0.7	0.4 ± 0.2	0.23 ± 0.04	0.37 ± 0.01	0.02 ± 0.0	37.0 ± 2.8	0.2 ± 0.1	3.5 ± 0.7
53	6.9 ± 1.8[b]	0.87 ± 0.07	15.3 ± 2.9	0.8 ± 0.1	0.22 ± 0.08	0.71 ± 0.15	0.13 ± 0.0	39.3 ± 3.3	2.9 ± 1.7	3.5 ± 3.6
54	20.3 ± 1.1	7.0 ± 0.56	23.6 ± 3.8	2.9 ± 1.1	0.30 ± 0.02	1.19 ± 0.04	0.20 ± 0.01	57.9 ± 13.2	27.1 ± 1.6	21.0 ± 7.7
55	14.8 ± 0.8	6.35 ± 0.95	21.9 ± 3.5	1.9 ± 0.6	0.26 ± 0.03	1.04 ± 0.03	0.20 ± 0.07	45.3 ± 7.5	14.0 ± 0.7	9.9 ± 4.7
56	15.3 ± 1.2	5.6 ± 1.4	25.8 ± 0.5	1.0 ± 0.4	0.46 ± 0.12	0.87 ± 0.12	0.19 ± 0.01	57.1 ± 4.8	26.0 ± 4.9	55.0 ± 5.7
57	0.94 ± 0.1	0.1 ± 0.0	1.5 ± 0.8	1.8 ± 0.3	0.24 ± 0.10	0.4 ± 0.1	0.06 ± 0.0	41.5 ± 3.5	1.1 ± 0.2	2.9 ± 0.3
58	19.6 ± 1.3	2.5 ± 0.3	28.3 ± 2.4	8.0 ± 1.4	0.2 ± 0.01	1.2 ± 0.1	0.2 ± 0.03	64.0 ± 5.7	11.0 ± 2.8	55.0 ± 7.1

[a] Data are means of two determinations. TPC = total polar components; FFA = free fatty acids; PV = peroxide value.
[b] French fries—discarded oils of company A are to be kept for further use for Hardees' products frying.

generally suggest that the longer the frying time and the higher the frying temperature the higher the TPC in discarded oils of traditional shops. The highest values for TPC were found in some of the oils used for fallafel frying. Oxygen exposure and prooxidant effect of fallafel (24) may be the main causes of the higher deterioration. Frankel *et al.* (4) reported 2 to 22% polar + noneluted materials in randomly collected samples of soybean and cottonseed oils used for frying fallafel but the length and conditions of frying were not mentioned. However, they reported much lower values for polar + noneluted materials in randomly collected samples of vegetable shortening (for frying doughnuts, chicken, french fries, and mixed products) and of partially hydrogenated vegetable oil (for frying mixed products) compared to the values reported in this study. The increase in polar components was reported for refined, bleached, deodorized (RBD) olein (8), corn oil (25), corn, sunflower and soybean oils and hydrogenated palm oil (26), the last of which had the lowest rate of increase in polar components. It has been suggested that TPC is the most reliable method for measuring fat deterioration during frying (1) and that 25–30% is the rejection point for frying oil (3,10). This might not be adopted for more saturated oils (palm oil, and partially hydrogenated and hydrogenated oils) investigated in this study because they are less susceptible to chemical changes compared to polyunsaturated oils during the frying process.

Table 2 and Table 3 show the increase in free fatty acids in frying oils, particularly those collected from the franchise companies and from most of the individual broast shops, all of which applied mainly closed frying systems that minimize moisture evaporation. The free fatty acids were formed by hydrolysis of triglycerides, which was promoted by the presence of food moisture and by oxidation (1), or by the reaction of oil with moisture formed during other deterioration reactions (13,14,27,28–30). However, the measurement of free fatty acids cannot determine suitability of frying oils for further use (31).

The peroxide and p-anisidine values of fresh and discarded frying oils are shown in Table 2 and Table 3. These two oxidation parameters were generally higher in palm oils than in other oils, particularly for those samples collected from traditional shops. Partially hydrogenated or hydrogenated oils were less susceptible to oxidation because of disappearance of the reactive double bonds in the fatty acid chains. Peroxide value may be less reliable for monitoring thermal deterioration (27,31,32) because of the rapid decomposition of peroxides that are formed during primary oxidation (31,33). However, the p-anisidine value is more reliable because it measures the secondary stage of oxidation or accumulation of secondary products (27,34). The possible drawback of p-anisidine value is that reactive aldehydic products can take part in polymerization (35).

The increase in the extinctions at 232 nm and 268 nm (Table 2 and Table 3) indicated the formation of conjugated compounds (dienes and trienes) due to the shift of the double bond during frying. Most oil samples with higher TPC were higher in dienes and trienes. These compounds can form polymers and an equilibrium between the rate of formation of conjugated dienes and the rate at which those compounds form polymers may occur during frying (13,14).

Linoleic/palmitic ratio in frying oils is shown in Table 2 and Table 3. The ratio was expected to decrease due to a decrease in linoleic acid by oxidation (14,26,34,36–38) and was considered a reliable indicator of fat deterioration during frying (37). However, in this study some discarded oil samples, particularly oils used for chicken or fish frying, showed higher linoleic/palmitic ratios than those of their corresponding fresh oils. Their fatty acid profile was altered, due possibly to the fat leached out from the food and/or to a decreased oxidation reaction.

Frying of food resulted in the darkening of oils (Table 2 and Table 3) because of oxidation and of the colored pigments from the foods which diffused into the oil during frying (1,13,14). In this study, fish and chicken caused more amber and reddish brown colors in frying media, particularly in palm oils collected from individual traditional or broast shops. Palm oils are known to darken more quickly compared to other oils (39) but this does not necessarily mean a reduction in quality. The viscosities of most discarded palm oils were higher than those of other discarded oils (Table 2 and Table 3). The increase in viscosity during fat frying was due to polymerization, which resulted in the formation of higher molecular weight compounds (carbon-to-carbon and/or carbon-to-oxygen-to-carbon bridges between fatty acids) (2,16,17,35,40).

Quick-test methods. Discarded oils increased in their readings of dielectric constants due to accumulation of polar molecules during oil breakdown (data not shown). The results of this study showed that the lowest (0.65) and the highest (8.4) Foodoil sensor readings corresponded to TPC values of 4.3 and 33.1%, respectively, in PO samples. The suggested rejection point of 25% TPC (3,10) corresponded to Foodoil sensor value of 5.4. In partially hydrogenated soybean oil and cottonseed oil (PHSOCO), the average TPC values of 6.9, 14.8, 15.3, and 20.3% (Table 2 and Table 3) corresponded to average values of 0.9, 2.7, 2.6, and 4.0 Foodoil sensor readings, respectively. HVO used for doughnut frying contained an average TPC value of 19.6% or a 3.7 Foodoil sensor reading. However, Croon *et al.* (20) found that Foodoil sensor values of 3.1 and 3.5 corresponded to polar components values of 27% and 29%, respectively, in high-stability frying oils such as palm and hydrogenated oils. Another study by Augustin *et al.* (8) on RBD olein showed that 27% polar components gave a dielectric constant reading of 3.7 on the Foodoil sensor. In this study, the correlation (c.f = 0.93) between Foodoil sensor and the standard TPC method was highly significant (Table 4). This is in agreement with the findings of other workers (5,14,20). The Foodoil sensor is considered a quick and accurate alternative method for TPC (1,19). However, calibrations and readings of the instrument become difficult in later stages of frying (32,41), possibly due to artifacts (water or fat extracted from the fried food) present in frying oils.

Oxifrit (RAU-Test) and Fritest diagnostic kits measure the degree of deterioration of discarded oils by visual estimation of reaction mixtures against diagnostic colors of each kit. Oxifrit and Fritest color readings of "Bad" indicated abused frying oils, while the readings of "Replace" indicated the right time for change. The color comparisons indicated that the reaction mixtures of 60–64% of the oil samples from traditional or broast shops were identical to diagnostic colors of "Bad" or "Replace," while those of franchise companies were all identical to the

TABLE 4

Pearson Correlation Coefficients (n = 142) Between the Ordinary Laboratory Methods and Quick-test Methods[a]

	A	B	C	D	E	F	G	H	I	J	K	L	M
A	1.00	—	—	—	—	—	—	—	—	—	—	—	—
B	0.93*	1.00*	—	—	—	—	—	—	—	—	—	—	—
C	0.77*	0.73*	1.00	—	—	—	—	—	—	—	—	—	—
D	0.75*	0.70*	0.94*	1.00	—	—	—	—	—	—	—	—	—
E	0.43**	0.40**	0.62*	0.64*	1.00	—	—	—	—	—	—	—	—
F	0.73*	0.71*	0.76°	0.73*	0.38**	1.00	—	—	—	—	—	—	—
G	0.28	0.23	0.45**	0.44**	0.32***	0.63*	1.00	—	—	—	—	—	—
H	0.67*	0.70*	0.51*	0.59*	0.43**	0.37***	−0.06	1.00	—	—	—	—	—
I	0.09	0.13	−0.00	−0.01	−0.13	−0.04	−0.30	0.41**	1.00	—	—	—	—
J	0.51**	0.58*	0.34***	0.30	0.06	0.41***	0.05	0.40***	0.22	1.00	—	—	—
K	−0.37***	−0.38***	−0.12	−0.09	−0.13	−0.10	−0.03	−0.27	−0.27	−0.20	1.00	—	—
L	0.63*	0.65*	0.46**	0.46**	0.27	0.40***	0.01	0.75*	0.44**	0.30	−0.39***	1.00	—
M	0.36***	0.38***	0.41**	0.40**	0.21	0.28	0.04	0.63*	0.32***	0.28	−0.04	0.70*	1.00

[a] A = Total polar components; B = Foodoil sensor; C = Oxifrit (RUA-Test); D = Fritest; E = Veri-Fry-TAM-150; F = Veri-Fry-FFA-500; G = acidity (%FFA); H = p-anisidine value; I = peroxide value; J = viscosity; K = C 18:2/C 16:0; L = absorbance at 232; M = absorbance at 268.

*Denotes significance at 0.001 (p<0.001).

**Denotes significance at 0.01 (p<0.01).

***Denotes significance at 0.05 (p<0.05).

color of "Replace." This shows the difference in determining the rejection point of frying oils between the franchise companies and individually owned restaurants, which lacked the testing equipment and trained technical personnel. Generally, oil samples with TPC values of more than 12% showed Oxifrit or Fritest reading of "Bad" or "Replace." The results of Croon *et al.* (20) showed that Oxifrit readings between "Bad" and "Replace" corresponded to polar components of 27–29%. However, such comparison might not be valid because of different foods and different frying procedures. A highly significant correlation coefficient of 0.94 (Table 4) was found between Oxifrit and Fritest, each of which corresponded relatively well to the TPC values and Foodoil sensor (Table 4). The coefficients of correlation among these four indicators were much like the findings of Croon *et al.* (20). According to recommendations of the German Society of Fat Science, fat is deteriorated when Fritest shows a diagnostic color of "Bad (verdorben)" (20). It was easier to compare the color of the reaction mixtures to the color scale of the Oxifrit than to that of Fritest (20) because of visual clarity.

The estimation of total alkaline materials (soaps) in discarded frying oils was measured by the Veri-Fry-TAM 150 diagnostic test kit. The developed color of the mixture (sample and reagent) was compared with a color scale consisting of five diagnostic colors, each of which corresponds to a range of total alkaline materials (soap, ppm). The accumulation of these materials in the frying oils was a result of the interaction of food materials with oil degradation products (21). Oils used for frying fish, chicken, fallafel, and Hardees' products seemed to contain more alkaline materials because the color of their reaction mixtures was between the diagnostic color of 4 (corresponding to 86–110 ppm soap) and the diagnostic color of 5 (corresponding to 111–150 ppm soap). Lower correlation coefficients were found between Veri-Fry-TAM-150 and the TPC method and Foodoil sensor, (Table 4). However, this test showed better correlation to Oxifrit and Fritest data (Table 4).

Veri-Fry-FFA 500 diagnostic test kit measured acidity (%FFA) in discarded frying oils. The color scale is similar to the previous kit for total alkaline material, where each color corresponds to a range of %FFA. The acidity in used frying oils arose from the hydrolysis of triglycerides in the presence of food moisture and from oxidation (1,28,29,31,34,35,40). Veri-Fry-FFA 500 correlated relatively well with the TPC, Foodoil sensor, Oxifrit and Fritest, respectively, but its correlation with Veri-Fry-TAM 150 was poor (Table 4).

Other relationships between frying oil quality indicators are shown in Table 4. Poor correlation was found between the TPC and acidity (%FFA), and this confirms the finding of Croon *et al.* (20). Peroxide value did not correlate with any other indicators but p-anisidine value (c.f = 0.4), which correlated relatively well with absorbance at 232 and 268 mm (Table 4). The correlation coefficients between C18:2/C16:0 ratio and TPC and Foodoil sensor, respectively, were poor and this contradicts the results of other workers (5,14), who reported high correlation coefficients (0.99) between these three parameters in RBD olein. The same workers also reported higher correlation coefficients between TPC and absorbance at 232 μm (0.90) and at 268 μm (0.97) in double-fractionated palm olein during heating or frying than those shown in Table 4 for the same parameters.

In view of the acceptance of TPC as the standard method, adopted by AOAC and IUPAC (12) and by DGF (41), and being the most reliable method for fat deterioration measurement during frying (1), linear regression equations between TPC and each of the individual methods were established (Table 5). However, each method has its own drawbacks and this makes it difficult to depend on a single procedure for evaluating the degree of discarded frying oil deterioration. The TPC method is of most use to researchers, since it is time-consuming, and requires equipment and highly skilled personnel. The quick-test methods need little technical expertise and can be done on-the-spot at restaurants and food-service institutions. The right decision of when to discard the frying oil would

TABLE 5

Relationship Between Total Polar Components (X) and Other Indicators of Frying Oil Deterioration ($n = 142$)

Indicator	Equation of regression line	P-value
Foodoil sensor	$Y = -0.642 + 0.236X$	0.0001*
Oxifrit (RUA-Test)	$Y = 1.174 + 0.113X$	0.0001*
Fritest	$Y = 1.231 + 0.090X$	0.0001*
Veri-Fry-TAM-150	$Y = 1.504 + 0.089X$	0.0042**
Veri-Fry-FFA-500	$Y = 0.282 + 0.150X$	0.0001*
Acidity (%FFA)	$Y = 0.289 + 0.102X$	0.0716
p-Anisidine value	$Y = 10.214 + 2.585X$	0.0001*
Peroxide value	$Y = 8.349 + 0.108X$	0.5530
Viscosity	$Y = 55.305 + 1.334X$	0.0013**
C18:2/C16:0	$Y = 0.384 - 0.005X$	0.0246***
Absorbance (232)	$Y = 0.709 + 0.050X$	0.0001*
Absorbance (268)	$Y = 0.253 + 0.007X$	0.0270***

*Denotes significance at 0.001 level ($p<0.001$).
**Denotes significance at 0.01 level ($p<0.01$).
***Denotes significance at 0.05 level ($p<0.05$).

minimize the cost as well as the deleterious effects on the quality of fried products and health.

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