International Food Research Journal 21(2): 1119-1124 (2014)
Journal homepage: *http://www.ifrj.upm.edu.my*

Impact of chicken nugget presence on the degradation of canola oil during frying

[1*]Ali, M. A., [2]Daud, A. S. M., [3]Latip, R. A., [3]Othman, N. H. and [4]Islam, M. A

[1]*Department of Chemistry, Faculty of Applied Science and Engineering, Rajshahi University of Engineering and Technology, Rajshahi-6204, Bangladesh*
[2]*Kilang Sawit Tenggaroh Timur, Felda Palm Industries Sdn Bhd, Karung Berkunci, Kota Tinggi, Johor Darul Takzim, Malaysia*
[3]*Sime Darby Research Sdn. Bhd., 42700 Banting Selangor, Malaysia*
[4]*Open School, Bangladesh Open University, Gazipur-1705, Bangladesh*

Article history

Received: 6 November 2013
Received in revised form: 16 December 2013
Accepted: 17 December 2013

Keywords

Canola oil
Frying oil
Deep-fat frying
Chicken nugget
Fatty acids

Abstract

The aim of the present study was to evaluate the effect of chicken nuggets addition on the degradation of canola oil during frying compared to the changes occurring when the same frying medium was simply heated at frying temperature as control. Heating or frying test was carried out at 185±5°C using electric fryer for 8 h/day for 3 consecutive days and the oil sample was collected every 4 h. The changes in fatty acids composition and physicochemical properties of the oil samples during frying and controlled heating experiments were monitored. In this study, refractive index, free fatty acid content, peroxide value, *p*-anisidine value, polar compounds and viscosity of the oils all increased, whereas iodine value and $C_{18:2}/C_{16:0}$ ratio decreased as heating or frying progressed. The percentage of linoleic acid tended to decrease, whereas the percentages of palmitic acid increased. Gas chromatography analysis revealed that adding chicken nuggets to heated canola oil led to higher decrease in the ratio of $C_{18:2}/C_{16:0}$ compared to what was measured when the fat alone was heated at frying temperature. The presence of chicken nuggets accelerates the formation of polymerization products and polar compounds in canola oil during frying.

Introduction

The chicken nuggets are being employed as the consumer products preferred as a fast food around the globe. It is prepared by using chicken meat, vegetable protein, gum and a fair proportion of chicken skin. After formulation, it is submerged in a frying medium to pre-fry before being packed. The choice of the frying medium for frying chicken nuggets may vary depending on the cost as well as the preference of the food manufacturer. During deep-fat frying, a large number of decomposition products are formed that influence the functional, sensory and nutritional quality of the oil and the product being fried (Stevenson *et al*., 1984). The types of compounds formed depend upon the food being fried, how the fryers are operated and maintained, and the frying medium oil. A number of volatile compounds formed during frying exhibit carcinogenic, mutagenic and genotoxic properties (Chiang *et al*., 1997; Chiang *et al.*, 1999). Generally, oil degradation products of molecular mass less than 1.8 KDa are volatile and the rest are non-volatile (Melton *et al.*, 1994). A literature survey shows that many factors can affect the chemical profile of an oil or fat during frying. These include processing variables and variables related to the frying medium as well as to the food being fried. Adding food to a fryer induces a considerable drop (quench) in the oil temperature, which cannot be easily replicated in the absence of food. Moreover, interactions between food and frying oil are an important aspect to look into understanding the deteriorative changes in frying oils. It has been reported earlier that more than 90% of the lipids in fried food came from the frying oil while more than 85% of the lipids in pre-fried food were released into the frying oil (Pérez-Camino *et al.*, 1991). Some research works related to the effect of adding foods on the quality characteristics of vegetable oils have been reported (Kalogianni *et al.*, 2009; Kalogianni *et al*., 2010; Lioumbas *et al*., 2012).

To date very few studies have been carried out on the chemical alteration of canola oil during frying of chicken/chicken nuggets. Talpur *et al.* (2009) identified the quality changes occurring during deep chicken frying in soybean, sunflower and canola oil and compared the frying stability of soybean, canola and sunflower oil under the same conditions. Comparatively sunflower oil was found to be more stable for chicken frying as compared to soybean and canola oil. Enríquez-Fernández *et al.* (2011)

*Corresponding author.
Email: *radwiya44@yahoo.com*

compared the stability of palm olein and a palm olein/canola oil blend during frying of chicken nuggets and French fries, and concluded that blending canola oil with palm olein led to a slower degradation to the obtained with palm olein. In the present study, efforts were made to determine the effect of adding chicken nuggets on the degradation of canola oil during repeated, discontinuous deep frying. The degradation of the oil under controlled heating condition was also studied by keeping the same operational conditions as those in deep frying except there was no food in the oil.

Material and Methods

Food materials and chemicals

Refined canola oil (Wintercorn Edible Products, Australia) and chicken nuggets were procured from local super market. The food material was kept in the refrigerator below 4°C for storage. All chemicals and solvents used were of analytical grade. *p*-Anisidine and silica gel were purchased from Merck (Darmstadt, Germany). Standards of fatty acid methyl esters were from Supelco Chemical Co. (Bellefonte, PA, USA). All other chemicals and solvents were from J. T. Baker (Phillipsburg, USA) or RCI Labscan Ltd. (Pathumwan, Thailand) unless otherwise stated.

Frying trials and oil sampling

Frying test was carried out using 2.5 L domestic electric fryer (Philips HD-6159, Malaysia). Fryer was switched on 10-15 min before beginning of frying each day to heat oil up to the desired frying temperature (185±5°C). Two frying cycles of 4 h were carried out with a 1 h interval between them. During each cycle, 8 batches of chicken nuggets (80 g) were fried. A total of 16 batches constituting two frying cycle, was performed in each day of frying. Frying session was lasted for 8 h/day for 3 consecutive days. The fryer was left uncovered throughout the frying operation; after frying switched off and the lid was put. The volume of oil was not replenished during the frying operation. Control samples were produced by heating the oil without any food in it using the same protocol as in operation for chicken nuggets. In total, two simulated operations were performed. The two operations were denoted as COCN (canola oil with chicken nuggets) and CO (canola oil without chicken nuggets). The oil samples (210 mL) were withdrawn at 4 h intervals and after cooling to room temperature, filtered with Whatman No. 4 filter paper and stored at –15°C until analysis. Initial physico-chemical analyses of the fresh canola oil were also carried out.

Fatty acids composition

Fatty acids of the oil samples were transesterified into their corresponding methyl esters following PORIM (PORIM, 1995) test method p3.4 prior to analysis by gas-liquid chromatography. Fatty acid composition was determined using an auto-system XL gas chromatograph (Perkin Elmer Incorporate, Massachusetts, USA) equipped with a SP-2340 (Supelco Inc., Bellefonte, PA, USA) fused silica capillary column (60 m x 0.25 mm i.d x 0.20 µm film thickness) and a flame ionization detector. Nitrogen was used as carrier gas with a flow rate of 20 mL/min at 20 psi. Initial oven temperature was set to 100°C, raised to 170°C at 20°C/min, then programmed to 230°C at 10°C/min, hold at 230°C for 7 min, and finally heated to 250°C at 30°C/min. The detector and injector temperatures were both maintained at 250°C. Methyl esters were quantified by comparing the retention times and peak area of the unknowns with known FAME standard mixtures.

Standard physicochemical analyses

AOCS recommended methods (AOCS, 1987) were used to determine refractive index (method Cc 7-25), FFA content (method Ca 5a-40), iodine value (method Cd 1b-87) and peroxide value (method Cd 8-53). p-Anisidine value (method p2.4) of the sample was measured by means of a Jenway 6305 Spectrophotometer (Barloworld Scientific Ltd., UK) according to the PORIM (PORIM, 1995) test method.

Viscosity measurement

Viscosity of the oil was measured by using a Brookfield DV–II+ viscometer (Brookfield Engineering Laboratories Inc., Middleboro, MA, USA). One milliliter of oil was placed on the plate of the viscometer with spindle S-42; the viscosity of the sample was read in cP (centipoise) directly from the viscometer, which was maintained at 40°C.

Total polar compounds (TPC) content

The TPC content was determined according to the standardized IUPAC method 2.507 (IUPAC, 1987) using a mixture of light petroleum ether/diethyl ether (87:13, v/v) as elution solvent.

Results and Discussion

During deep frying, fatty acid profiles of the frying oils all changed due to cyclization, polymerization, and pyrolytic, hydrolytic, oxidative, and other chemical reactions promoted by frying conditions. Monitoring fatty acid profiles during frying provides only limited

Table 1. Fatty acids composition (%) of canola oils during frying and controlled heating

Oil sample	Frying/ Heating time (h)	$C_{12:0}$	$C_{14:0}$	$C_{16:0}$	$C_{16:1}$	$C_{18:0}$	$C_{18:1}$	$C_{18:2}$	*Trans* $C_{18:2}$	$C_{18:3}$	$C_{20:0}$	SFA	MUFA	PUFA	$C_{18:2}/C_{16:0}$
CO	0	0.05 ± 0.00	0.07 ± 0.00	4.71 ± 0.00	0.17 ± 0.00	1.95 ± 0.01	66.40 ± 0.17	19.43 ± 0.05	0.04 ± 0.01	5.85 ± 0.07	1.24 ± 0.00	8.02	66.57	25.32	4.12
	4	0.05 ± 0.00	0.08 ± 0.00	5.03 ± 0.01	0.17 ± 0.00	2.07 ± 0.01	66.98 ± 0.13	18.28 ± 0.05	0.03 ± 0.02	6.01 ± 0.03	1.23 ± 0.02	8.48	67.15	24.32	3.63
	8	0.05 ± 0.00	0.08 ± 0.00	5.08 ± 0.01	0.18 ± 0.01	1.96 ± 0.00	67.17 ± 0.13	18.32 ± 0.06	0.05 ± 0.01	5.84 ± 0.02	1.19 ± 0.01	8.36	67.35	24.21	3.60
	12	0.05 ± 0.00	0.09 ± 0.00	5.08 ± 0.02	0.18 ± 0.01	2.04 ± 0.05	67.27 ± 0.15	18.18 ± 0.07	0.04 ± 0.00	5.78 ± 0.00	1.21 ± 0.19	8.47	67.45	24.00	3.57
	16	0.05 ± 0.00	0.08 ± 0.00	5.09 ± 0.00	0.17 ± 0.00	2.04 ± 0.04	67.56 ± 0.02	18.01 ± 0.09	0.04 ± 0.02	5.72 ± 0.07	1.14 ± 0.10	8.40	67.73	23.77	3.53
	20	0.06 ± 0.00	0.09 ± 0.02	5.26 ± 0.02	0.19 ± 0.01	1.98 ± 0.01	68.33 ± 0.12	17.56 ± 0.02	0.05 ± 0.00	5.25 ± 0.03	1.14 ± 0.13	8.53	68.52	22.86	3.33
	24	0.06 ± 0.00	0.09 ± 0.02	5.31 ± 0.02	0.19 ± 0.01	1.99 ± 0.00	68.52 ± 0.12	17.46 ± 0.03	0.07 ± 0.01	5.01 ± 0.00	1.11 ± 0.09	8.56	68.71	22.54	3.29
COCN	0	0.05 ± 0.00	0.07 ± 0.00	4.71 ± 0.00	0.17 ± 0.00	1.95 ± 0.01	66.40 ± 0.17	19.43 ± 0.05	0.04 ± 0.01	5.85 ± 0.07	1.24 ± 0.00	8.02	66.57	25.32	4.12
	4	0.06 ± 0.00	0.14 ± 0.00	7.37 ± 0.00	0.16 ± 0.00	2.12 ± 0.00	65.02 ± 0.09	18.54 ± 0.03	0.04 ± 0.02	5.23 ± 0.05	1.22 ± 0.02	10.91	65.18	23.81	2.51
	8	0.06 ± 0.00	0.18 ± 0.00	9.06 ± 0.03	0.18 ± 0.02	2.20 ± 0.05	64.77 ± 0.02	17.75 ± 0.02	0.04 ± 0.00	4.70 ± 0.00	0.94 ± 0.00	12.44	64.99	22.49	1.96
	12	0.07 ± 0.00	0.22 ± 0.00	10.25 ± 0.01	0.17 ± 0.00	2.21 ± 0.00	64.26 ± 0.05	17.27 ± 0.05	0.06 ± 0.01	4.37 ± 0.05	1.01 ± 0.07	13.76	64.43	21.70	1.68
	16	0.07 ± 0.00	0.22 ± 0.00	10.26 ± 0.05	0.18 ± 0.00	2.28 ± 0.05	64.20 ± 0.19	17.21 ± 0.03	0.06 ± 0.01	4.36 ± 0.03	1.08 ± 0.15	13.91	64.38	21.63	1.68
	20	0.07 ± 0.00	0.26 ± 0.00	12.04 ± 0.03	0.18 ± 0.00	2.42 ± 0.09	64.00 ± 0.17	16.07 ± 0.03	0.05 ± 0.00	3.79 ± 0.02	1.01 ± 0.11	15.80	64.18	19.91	1.33
	24	0.08 ± 0.00	0.30 ± 0.00	13.85 ± 0.05	0.18 ± 0.01	2.45 ± 0.00	63.24 ± 0.11	15.39 ± 0.02	0.05 ± 0.00	3.35± 0.03	1.01 ± 0.16	17.69	63.42	18.79	1.11

Each value in the table represents the mean of two replicates ± SD.

Table 2. Refractive index and FFA value of canola oils during frying and controlled heating

Frying/Heating time (h)	Refractive index		FFA (%)	
	Controlled heating (CO)	Frying with chicken nuggets (COCN)	Controlled heating (CO)	Frying with chicken nuggets (COCN)
0	1.4457 ± 0.001	1.4457 ± 0.001	0.15 ± 0.05	0.15 ± 0.05
4	1.4482 ± 0.001	1.4621 ± 0.003	0.14 ± 0.01	0.22 ± 0.00
8	1.4741 ± 0.002	1.4736 ± 0.001	0.16 ± 0.00	0.18 ± 0.00
12	1.4834 ± 0.002	1.4874 ± 0.002	0.17 ± 0.00	0.20 ± 0.04
16	1.4909 ± 0.002	1.5101 ± 0.002	0.18 ± 0.01	0.28 ± 0.01
20	1.5071 ± 0.001	1.5172 ± 0.001	0.23 ± 0.01	0.36 ± 0.02
24	1.5186 ± 0.001	1.5235 ± 0.001	0.25 ± 0.02	0.42 ± 0.00

Each value in the table represents the mean of two replicates ± SD.

information about these compositional changes that are associated with oil degradation (Xin-Qing *et al.*, 1999). The changes of fatty acids composition in the fresh and used oils are shown in Table 1. Oleic acid was major in fresh canola oil (66.40%) followed by linoleic acid (19.43%) and linolenic (5.85%) and palmitic (4.71%) acids at lesser concentration. In this study, it has been shown that heating/frying of oil caused a fast decrease in more USFAs (unsaturated fatty acids) than less unsaturated or saturated fatty acids. During heating or frying of chicken nuggets, the percentage of linoleic and linolenic acids tended to decrease, whereas the percentage of palmitic acid increased, probably due to PUFA (polyunsaturated fatty acid) degradation. A similar trend was found by Sebedio *et al.* (1990) in soybean oil during frying frozen potatoes. The higher rate of increment of palmitic acid was observed in frying operation than that in heating operation as the result of the adding palmitic acid from chicken nuggets. The percentage of oleic acid was found to be increased during frying of chicken nuggets and decreased during heating. It is worth mentioning that the amount of trans C18:2 was present in the oils in small amounts even after 24 h of heating or frying. The ratios of C18.2/C16:0 are presented in Table 1. The ratio C18.2/C16:0 has been suggested as a valid indicator of the level of PUFA deterioration (Normand *et al.*, 2001). In all of the oil samples, these ratios declined during the three consecutive days of heating or frying. The percent reductions of the ratios $C_{18.2}/C_{16:0}$ in the CO and COCN oil treatments were 20.14 and 73.05 respectively. The smallest change (decrease) in the $C_{18.2}/C_{16:0}$ ratio belonged to the CO. This means that oxidation process progressed more rapidly in the frying process as compared to the controlled heating process.

Refractive index (RI) values of treated oils were increased as the number of heating or frying performed by the oils increased (Table 2). A similar result was obtained by Leyla *et al.* (2009) who heated hazelnut, olive, grape seed and sunflower oils at frying temperature (175±5°C) for 5 days. RI increases with an increase in polymerization, molecular cohesiveness among the components of increased chain length, saturation of carbon-carbon double bonds, moisture in food and opaqueness and turbidity (Kress Rogers *et al.*, 1990). The increment of RI value after 24 h treatment was found to be slightly higher in COCN (5.38%) than that of CO (5.04%). Free fatty acids (FFA) are an indicator of hydrolytic rancidity; as the time increased, the FFA level of oils was increased (Table 2). At the end of frying chicken nuggets, the rate of increment of FFA in oil was found to be higher (180%) as compared to oil (66.66%) without chicken nuggets. Enríquez-Fernández *et al.* (2011) observed that the frying of chicken nuggets caused greater amounts of FFA compared to the frying of French fries. The reason may be due to the different food materials having different composition (French fries mainly carbohydrates, and chicken nuggets contain protein) which may affect the degradation of the oils in different way. In the present study, all values were below 1.3-2.5%, values for discarding used oils (Paul and Mittal, 1996). Using FFA content as an indicator of frying oil degradation and of fried food quality is still controversial. In practice, FFA levels may not affect frying performance or have significant adverse effects on health or sensory evaluation (Xin-Qing *et al.*, 1999). Xin-Qing *et al.* (1999) recommended not using FFA as the sole indicator for determining the life of frying oil. The present result indicates that hydrolytic reactions induced under the frying conditions were found to be faster as compared to those under the heating conditions.

Table 3 shows the changes in peroxide value (PV) of the canola oils over 24 h of heating/frying at 185±5°C. There was an initial sharp increase in the PV for both CO and COCN after which the rate

Table 3. Peroxide value, *p*-Anisidine value and iodine value of canola oils during frying and controlled heating

Frying/ Heating time (h)	Peroxide value		*p*-Anisidine value		Iodine Value	
	Controlled heating (CO)	Frying with chicken nuggets (COCN)	Controlled heating (CO)	Frying with chicken nuggets (COCN)	Controlled heating (CO)	Frying with chicken nuggets (COCN)
0	2.84 ± 0.03	2.84 ± 0.03	3.11 ± 0.71	3.11 ± 0.71	103.34 ± 0.21	103.34 ± 0.21
4	16.08 ± 1.32	22.41 ± 2.04	35.27 ± 0.21	35.67 ± 0.14	101.20 ± 0.25	100.53 ± 0.72
8	20.12 ± 0.10	25.14 ± 0.14	72.36 ± 1.55	62.04 ± 0.49	98.39 ± 0.70	99.12 ± 0.32
12	26.89 ± 2.12	9.53 ± 1.17	107.78 ± 2.08	120.31 ± 0.42	96.61 ± 0.99	98.37 ± 0.37
16	20.95 ± 1.15	8.67 ± 1.34	131.61 ± 1.86	142.10 ± 0.60	95.82 ± 1.32	98.24 ± 2.49
20	19.35 ± 2.92	7.47 ± 1.83	137.33 ± 0.23	164.02 ± 0.77	95.06 ± 0.48	96.48 ± 0.23
24	18.82 ± 1.22	6.81 ± 0.22	133.97 ± 0.45	157.28 ± 0.34	94.64 ± 1.24	95.70 ± 1.72

Each value in the table represents the mean of three replicates ± SD.

Table 4. Total polar compound and viscosity of canola oils during frying and controlled heating

Frying/ Heating time (h)	Total polar compound (%)		Viscosity (cP)	
	Controlled heating (CO)	Frying with chicken nuggets (COCN)	Controlled heating (CO)	Frying with chicken nuggets (COCN)
0	2.49 ± 0.60	2.49 ± 0.60	30.01 ± 0.25	30.01 ± 0.25
4	2.64 ± 0.85	2.00 ± 0.36	33.09 ± 0.42	33.45 ± 0.73
8	5.87 ± 0.29	8.27 ± 0.08	33.71 ± 0.27	35.07 ± 0.62
12	8.66 ± 0.81	10.68 ± 0.40	35.91 ± 0.63	37.05 ± 0.34
16	16.59 ± 0.25	19.91 ± 0.16	37.75 ± 0.58	38.40 ± 0.86
20	22.17 ± 0.34	20.49 ± 0.18	41.01 ± 0.93	44.63 ± 0.37
24	23.75 ± 0.23	27.82 ± 0.27	43.65 ± 0.65	49.11 ± 0.66

Each value in the table represents the mean of three replicates ± SD.

slowed down. Peak values were attained as follows: CO (26.89) and COCN (25.14). The PV decreased in both the sample after the peak was reached. The PV peak for the CO was reached after 8 h as compared to 4 h in cases of COCN. For peroxides, the data confirms the results showed in early studies (Tsaknis and Lalas, 2002; Abdulkarim *et al*., 2007), with an increase in the peroxides until a maximum is reached, followed by a decrease of those compounds due to their reactions and degradations to other compounds such as aldehydes and ketones, as secondary compounds derived from the oxidation. However, during the frying operation, both the samples exceeded the acceptable level of 10 mequiv O_2 kg^{-1} given by the Guidelines of the German Food Codex as the limit for edible fats and oils (Mariod *et al.*, 2006). Compared to PV, the *p*-Anisidine value (*p*-AV) is a more reliable and meaningful test as it measures the secondary oxidation products, which are more stable during the heating process (Al-Kahtani, 1991). According to the literature, the *p*-AV should be less than 10 for good quality oil (Che Man and Hussin, 1998). The initial *p*-AV value in the fresh canola oil was no higher than 5 unit, which attest to the high quality of oils used in this study (Table 3). The *p*-AV in all the oils increased with heating/frying time and then decreased slightly after 20 h and other researchers (Aladedunye and Przybylski, 2009; Tiffany *et al.*, 2009) detected similar trend for some vegetable oils and may be attributed to the role it plays in the changes in carbonyle content or to the elevated used temperatures that probably caused the diminishing of these labile components (Tyagi and Vasishtha, 1996). When frying with chicken nuggets, the change in p-AV was found to be higher suggested the fastest degradation rate in the frying ones as compared to the controlled heated oil samples. A progressive decrease in unsaturation was found in all oil samples by determining iodine value (IV) during heating or frying (Table 3). This decrease in unsaturation can be attributed to the destruction of double bonds by oxidation, scission, and polymerization (Cuesta *et al.*, 1991). After 24 h treatment, the decrease amount in IV of COCN (7.39%) was slightly lower than that of CO (8.42%).

Formation of polar compounds indicates oil deterioration and is strongly related with the primary and secondary oxidation that takes place during frying (Sibel and Sebnem, 2011). The amount of total polar compounds (TPC) in the oil samples increased with the time increment and the rates of increments were different from each other (Table 4). After 24 h of heating/frying, the final TPC levels were found to be 23.75% in CO and 27.82% in COCN. However, the total polar contents accumulated after 24 h of frying of chicken nuggets slightly exceeded the limit 27% based on the German standard (Billek *et al.*, 1978). Hence, the faster increase in TPC levels was observed when chicken nuggets were fried. Enríquez-Fernández *et al*. (2011) observed the higher TPC when chicken nuggets were fried compared to oils with French fries. As can be seen from Table 4, the viscosity of oils increased with different rates over the 24 h of the heating or frying operation. Increase in viscosity was caused due to the formation of high molecular weight polymers. The more viscous the frying oil, the higher the degree of deterioration (Abdulkarim *et al*., 2007). In this study, the viscosity of the CO was lower than that of COCN at each of corresponding treatment times which clearly revealed the higher deteriorative effect of oxidation and polymerization of canola oil during frying of chicken nuggets. Kalogianni *et al.* (2009) stated that the presence of potatoes during frying in palm oil increased the concentration of polymerization products and polar compounds compared to oils without potatoes significantly.

Conclusion

Results obtained during frying of chicken nuggets were compared with those from the experiment where just the oil is exposed to heating at frying temperature. The present study is the systematic work assessing the effect of real food presence in the heated oil and our results revealed adding chicken nuggets into heated canola oil markedly increased the concentration of decomposition products compared to oils without chicken nuggets. However, the $C_{18:2}$/ $C_{16:0}$ ratio decreased in all oil samples and the highest decreased amount was observed for the oil used in

frying chicken nuggets. Further studies can be done to monitor the effect of minor components present in chicken nuggets on the rate of degradation of canola oil.

References

Abdulkarim, S. M., Long, K., Lai, O. M., Muhammad, S. K. S. and Ghazali, H. M. 2007. Frying quality and stability of high-oleic Moringa oleifera seed oil in comparison with other vegetable oils. Food Chemistry 105: 1382–1389.

Aladedunye, F. and Przybylski, R. 2009. Protecting oil during frying: A comparative study. European Journal of Lipid Science and Technology 111: 893–901.

Al-Kahtani, H. 1991. Survey of quality of used frying oils from restaurants. Journal of American Oil Chemists Society 68: 857–862.

AOCS. 1987. Official Methods and Recommended Practices of the American Oil Chemists' Society. 4th ed., Champaign: AOCS press.

Billek, G., Guhr, G. and Waibel, J. 1978. Quality assessment of used frying fats: A comparison of four methods. Journal of American Oil Chemists Society 55: 728–732.

Che Man, Y. B. and Hussin, W. R., 1998. Comparison of the frying performance of refined, bleached and deodorized palm olein and coconut oil. Journal of Food Lipid 5: 197–210.

Chiang, T. A., Wu, P. F. and Ko, Y. C. 1999. Identification of carcinogens in cooking oil fumes. Environmental Research 81: 18–22.

Chiang, T. A., Wu, P. F., Wang, L. F., Lee, H., Lee, C. H. and Ko, Y. C. 1997. Mutagenicity and polycyclic hydrocarbon content of fumes from heated cooking oils produced in Taiwan. Mutation Research- Fundamental and Molecular Mechanisms of Mutagenesis 381: 157–161.

Cuesta, C., Sanchez-Muniz, F. J. and Hernandez, I. 1991. Evaluation of nonpolar methyl esters by column and gas chromatography for the assessment of used frying olive oils. Journal of American Oil Chemists Society 68: 443–445.

Enríquez-Fernández, B. E., Álvarez De La, C. Y. Y. L. and Sosa-Morales, M. E. 2011. Comparison of the stability of palm olein and a palm olein/canola oil blend during deep-fat frying of chicken nuggets and French fries. International Journal of Food Science and Technology. 46: 1231–1237.

IUPAC. 1987. Standard Methods for the Analysis of Oils, Fats and Derivatives. 7th Revised and Enlarged ed., Oxford: Blackwell Scientific Publication.

Kalogianni, E. P., Karastogiannidou, C. and Karapantsios, T. D. 2009. Effect of the presence and absence of potatoes under repeated frying conditions on the composition of palm oil. Journal of American Oil Chemists Society 86: 561–571.

Kalogianni, E. P., Karastogiannidou, C. and Karapantsios, T. D. 2010. Effect of potato presence on the degradation of extra virgin olive oil during frying. International Journal of Food Sciences and Technology 45: 765–775.

Kress Rogers, E., Gillat, P. N. and Rosel, J. B. 1990. Development and evaluation of a novel sensor for the in situ assessment of frying oil quality. Food Control 13: 163–178.

Leyla, T., Mehmet, S. A. and Emin, Y. 2009. Physicochemical changes in hazelnut, olive pomace, grape seed and sunflower oils heated at frying temperatures. Food Science and Technology Research 15: 519–524.

Lioumbas, J. S, Ampatzidis, C. and Karapantsios, T. D. 2012. Effect of potato deep-fat frying conditions on temperature dependence of olive oil and palm oil viscosity. Journal of food Engineering 113: 217–225

Mariod, A., Matthäus, B., Eichner, K. and Hussein, I. H. 2006. Frying quality and oxidative stability of two unconventional oils. Journal of American Oil Chemists Society 83: 529–538.

Melton, S. L., Jafar, S., Sykes, D. and Trigiano, M. K. 1994. Review of stability measurements for frying oils and fried food flavour. Journal of American Oil Chemists Society 71: 1301–1312.

Normand, L., Eskin, N. A. M. and Przybylski, R. 2001. Effects of tocopherols on the frying stability of regular and modified canola oils. Journal of American Oil Chemists Society 78: 369–373.

Paul, S. and Mittal, G. S. 1996. Dynamics of fat/oil degradation during frying based on optical properties. Journal of Food Engineering 30: 389–403.

Pérez-Camino, M. C., Márquez-Ruiz, G., Ruiz-Méndez, M. V. and Dobarganes, M. C. 1991. Lipid changes during frying of frozen prefried foods. Journal of Food Sciences 56: 1644–1647.

PORIM. 1995. PORIM Test Methods. Palm Oil Research Institute of Malaysia, Ministry of Primary Industries, Malaysia.

Sebedio, J. L., Bonpunt, A., Grandgirard, A. and Prevost, J. 1990. Deep fat frying of frozen pre-fried french fries: influence of the amount of linolenic acid in the frying medium. Journal of Agricultural and Food Chemistry 38: 1862–1867.

Sibel, K. and Sebnem, S. 2011. Changes in total polar compounds, peroxide value, total phenols and antioxidant activity of various oils used in deep fat frying. Journal of American Oil Chemists Society 88: 1361–1366.

Stevenson, S. G., Vaisley-Genser, M. and Eskin, N. A. M. 1984. Quality control in the use of deep frying oils. Journal of American Oil Chemists Society 61: 1002–1008.

Talpur, M. Y., Sherazi, S. T. H., Mahesar, S. A. and Kandhro A. A. 2009. Effects of chicken frying on soybean, sunflower and canola oils. Pakistan Journal of Analytical and Environmental Chemistry 10: 59–66.

Tiffany, T., Peitz, M., Clark, D., Billiter, K. and Kickle B. 2009. Laboratory frying evaluation of palm olein and palm olein domestic vegetable oil blends. 6th Global Oils and Fats Forum, New Orleans, LO, October 5-6,

2009.
Tsaknis, J. and Lalas S. 2002. Stability during frying of Moringa oleifera seed oil variety ‘‘Periyakulam 1”. Journal of Food Composition and Analysis 15: 79–101.
Tyagi, V. K. and Vasishtha, A. K. 1996. Changes in the characteristics and composition of oils during deep-fat frying. Journal of American Oil Chemists Society 73: 499–506.
Xin-Qing, X., Viet, H. T., Martin, P., Keith, W. and Philip S. 1999. Chemical and physical analyses and sensory evaluation of six deep-frying oils. Journal of American Oil Chemists Society 76: 1091–1099.