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Effects of oil-water mixed frying and pure-oil frying on the quality characteristics of soybean oil and chicken chop

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Abstract

The effects of oil-water mixed frying (OWF) and pure-oil frying (POF) on changes in quality characteristics of soybean oil and chicken chop during six days of frying were comparatively investigated. The results showed that the changes in specific extinction coefficients, *p*-anisidine value, carbonyl value, viscosity and color of soybean oil were more pronounced in the case of POF, indicating that oil oxidative and polymeric degradation was retarded by OWF. Concerning fat content of chicken chop, lower ($p<0.05$) values were observed in the last three days in the case of OWF than POF. Meanwhile, OWF led to lower acrylamide formation in chops during the six days. Sensory evaluation showed that OWF provided chops with five attributes similar to those of chops fried by POF on the first day. As frying days increased, the decreases in scores for color, odor, flavor and overall acceptability were less in the case of OWF. In conclusion, OWF could be a worthwhile alternative for retarding oil deterioration and producing healthier and higher quality fried meat products.

Keywords: oil-water mixed frying; soybean oil; chicken chop; oil degradation; acrylamide.

Practical Application: Oil-water mixed frying should be applied to retard oil degradation and obtain higher quality products.

1 Introduction

Frying is one of the most common food preparation techniques that is defined as a process of drying and cooking of food by immersing food in oil at a high temperature, usually 165-190 °C (Moreira, 2014). During the process, the heat and simultaneous mass transfer of food, oil and air promote a variety of physical and chemical changes, such as water loss, oil uptake, crust formation, color change, flavor development, starch gelatinization and oil oxidation (Nelson et al., 2013; Lazarick et al., 2014). These changes lead to the development of golden brown color, attractive fried aroma, savory flavor, crispy texture and juicy taste in fried products and improve the overall palatability of the products.

Due to its operational simplicity, economic viability, high versatility and its ability to create distinctive sensory characteristics in foods that are highly appreciated by consumers, frying is extensively employed in both domestic and industrial sectors (Teruel et al., 2015). Continuous and repeated use of frying oil is a common practice to cut expenses (Aladedunye & Przybylski, 2013). However, oil is subject to high heat, oxygen (from either air or food) and moisture (from food) for extended periods of time, resulting in a complex series of reactions involving oxidation, hydrolysis, isomerization and polymerization (Zhang et al., 2012). These reactions give rise to deterioration of oil composition (Brühl, 2014), and subsequent generation of a wide variety of volatile and nonvolatile compounds (Choe & Min, 2007), which ultimately alter the sensorial, nutritional and functional properties of the oil (Zhang et al., 2012; Aladedunye & Przybylski, 2013; Crosa et al., 2014). Since food absorbs a remarkable amount of oil during frying, making oil an ingredient of the final product (Al-Khusaibi et al., 2012), oil degradation has adverse effects not only on properties of fried foods, such as sensory attributes, nutrition and shelf-life (Dobarganes et al., 2000; Pawar et al., 2013; Aladedunye, 2015), but also on food safety, thereby affecting human health (Stier, 2013; Urbančič et al., 2014; Wang et al., 2015).

In recent decades numerous studies have been undertaken with the aim of mitigating the rate of oil deterioration during frying to ensure the quality and safety of fried foods. In view of frying method affecting the extent of oil deterioration and the overall quality of oil (Zhang et al., 2012; Aladedunye, 2015), it is important to develop alternative technologies to conventional frying, meanwhile maintaining fried foods' desirable sensory characteristics. Among possible methods, oil-water mixed frying is to use the mixture of oil and water in a fryer. Due to the insolubility and the different density between oil and water, the mixture layers themselves, leaving oil in the upper layer and water in the lower section. Galvanothermy tubes are placed horizontally in the middle of oil layer to only heat the

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oil. Coolers are placed at the interface of oil and water where the temperature is kept below 55 °C. In this way, food residues leave the high-temperature oil before carbonization and descend to water throughout the frying process, thereby being removed with water through plughole of the fryer in time. Oil-water mixed frying has several unique properties, such as partition temperature control, automatic filtration and self-cleaning. However, almost no reports are available on the effect of oil-water mixed frying on quality characteristics of frying oils and fried products.

Therefore, the objective of the present study was to evaluate the effect of oil-water mixed frying on changes in quality characteristics of soybean oil and chicken chop during six-day frying experiment. Conventional pure-oil frying was used for comparative studies. The degradation of oil quality was monitored by various chemical parameters (specific extinction coefficients, *p*-anisidine value, carbonyl value and free fatty acids) and physical parameters (viscosity and CIELAB color). The alterations of quality characteristics of chicken chop were assessed by analyzing fat content, acrylamide concentration and sensory property.

2 Materials and methods

2.1 Materials and chemicals

Refined soybean oil was supplied by Yihai Kerry Grain and Oil Co., Ltd. (China). Frozen deboned skinless chicken breasts were purchased from New Hope Liuhe Co., Ltd. (China) and kept frozen at –20 °C until being used. Batter and Breading ingredients were procured from Shuangying Food Co., Ltd. (China) and Jin Huanghua Food Co., Ltd. (China), respectively. All chemicals and solvents used were of analytical grade and obtained from Sinopharm Chemical Regent Co., Ltd. (China).

2.2 Preparation of chicken chops

The chicken chops were experimentally manufactured following commercial practices for fried products. At first, frozen chicken breasts were thawed at 4 °C for 24 h. After removal of external fat, fascia and separable connective tissue, chicken breasts were cut manually into characteristic shapes of chop (7 × 6 × 1.5 cm), each weighing 65 g. The cut chops were thoroughly mixed with marinade with the ratio of 10:3 meat to marinade (w/v), and they were then subjected to vacuum continuous tumbling marination using a ESK-125 tumbler (Kakona Gmbh Company, Germany). The conditions of tumbling marination were as follows: time 1.5 h, revolving speed 7 revolutions per minute, vacuum 80% and temperature 2 °C. The marinade solution was prepared by dissolving in water 50 g L^{-1} salt, 30 g L^{-1} gourmet powder, 55 g L^{-1} white granulated sugar, 15 g L^{-1} white pepper powder, 8 g L^{-1} sodium pyrophosphate, 8 g L^{-1} sodium tripolyphosphate and 4 g L^{-1} sodium hexametaphosphate. After tumbling marination, the chops with remaining marinade were left for static marination for 1 h at 4 °C. Thereafter, the chops were dipped into batter suspension for 30 s and allowed to drip for 8 s, and then coated with breading ingredients. The batter suspension was prepared by mixing batter with water at 10 g/15 mL. At last, the weight of each battered and breaded chicken chop was checked to have a uniform range of 105 ± 3 g.

2.3 Frying experiments

Oil-water mixed frying (OWF)

OWF was conducted in a professional oil-water mixed fryer of 20 L oil capacity (BYZG-20, Expro Machinery Engineering Co., Ltd., China), which initially was filled with 18 L of fresh soybean oil and right amount of clean water up to the water line of the fryer. Eight batches of chicken chops were fried each day for a total of six consecutive days, with each batch containing six chops. Once a batch of chops finished frying, the next batch was started. The chops were fried at 170 °C for 3.5 min and drained for 2 min to eliminate the excess surface oil. The core temperature of the fried chop was 80 ± 2 °C, as monitored by a Testo 108 thermometer (Testo Inc., Germany). Each day, the fourth to sixth batches of fried chops were allowed to cool to 40 °C and collected for sensory analysis, and the seventh and eighth batches were allowed to cool to room temperature (25 °C) for other analyses.

Each day, at the end of the eighth batch, the fryer was shut off and the oil was cooled to room temperature. Then the plughole of the fryer was turned on to make water with food residues outflow from the fryer. Thereafter, 240 mL of oil was filtered to remove any solid debris and stored in dark colored glass bottles without headspace at –20 °C to avoid subsequent alterations for further analysis. Before commencing frying every second day, clean water was poured into the fryer to the initial level and the oil was not replenished.

Pure-oil frying (POF)

In the case of POF, 9 L of fresh soybean oil was placed in a commercial temperature-controlled fryer (China). A batch of three chicken chops was fried for 3.5 min at 170 °C and drained for 2 min, and eight frying batches were performed per day for six consecutive days without any oil replenishment. The core temperature of fried chop was 80 ± 2 °C. At the end of each day, the oil was cooled to room temperature and 120 mL of oil was filtered to remove any solid debris and stored in dark colored glass bottles without headspace at –20 °C. The fourth to eighth batches of pure-oil fried chops were sampled following the same procedure as described in oil-water mixed frying experiment.

2.4 Analyses of fresh and fried soybean oil (day 0 to 6)

Chemical analyses

The spectrophotometric measurements at 232 nm and 268 nm, expressed as specific extinction coefficients K_{232} and K_{268}, were carried out by ISO 3656 (International Organization for Standardization, 2011). The *p*-anisidine value (AnV) was analyzed with reference to AOCS Method Ca 8-53 (American Oil Chemists' Society, 2004). Carbonyl value (CV), a measure of carbonyl compounds, was determined following the method developed by Endo et al. (2001), using 2-propanol and 2,4-decadienal as solvent and standard, respectively (Farhoosh & Moosavi, 2006). The results were expressed in micromoles of 2,4-decadienal per gram of oil. Free fatty acids (FFA), expressed as free oleic acid percentage, was determined using AOCS Method Ca 5a-40 (American Oil Chemists' Society, 2004).

Physical analyses

Rheological investigation of oil was conducted with a MCR-301 controlled stress rheometer (Anton Paar GmbH, Austria) with parallel plates (50 mm diameter) at 25 °C. The apparent viscosity was measured at a constant shear rate of 100 s^{-1}. The rheometer controls the sample's temperature with a Peltier bottom plate and a thermally regulated hood accessory. For color measurement, a CR-400 colorimeter (Konica Minolta Co., Japan) was used with D65 illuminant and 10° standard observer. According to the CIELAB system, CIE L* (lightness) and b* (yellowness) values were recorded.

2.5 Analyses of fried chicken chops (day 1 to 6)

Fat content in fried chicken chops was determined by Soxhlet extraction in accordance with AOAC 991.36 (Association of Official Analytical Chemistry, 2000). Acrylamide content was determined by HPLC according to the method developed by Sun (2012).

Sensory evaluation was carried out by eight panelists who were faculty members and graduate students in the College of Food Science and Technology and were trained in accordance with ISO 8586-1 (International Organization for Standardization, 1993). The chop samples were cooled to 40 °C, codified with three-digit random numbers and presented individually to the panelists along with water to cleanse panelists' palates between samples. Panelists assessed various attributes: color, odor, flavor, texture and overall acceptability, with 9-point hedonic scale (1, dislike extremely to 9, like extremely). A sensory score of 5 was taken as the borderline of acceptability.

2.6 Statistical analysis

All frying experiments and analytical determinations were performed in triplicate (n = 3). Data were presented as Mean ± SD and statistically analyzed by one-way ANOVA or general linear model using SAS 8.1 version (SAS Inc., Chicago, IL, USA). Significant differences between frying methods (p<0.05) were determined by t-test and significant differences among frying days (p<0.05) were determined by Duncan's multiple-range test.

3 Results and discussion

3.1 Effects of frying methods on physicochemical properties of soybean oil

Specific extinction coefficients

The levels of specific extinction coefficients, K_{232} and K_{268}, provide sensitive indications of the degree of oil oxidative deterioration. The K_{232} is highly associated with the amount of conjugated dienes produced by primary oxidation of polyunsaturated fatty acids (Nehdi, 2011). Whereas the K_{268} is more correlated to the presence of secondary oxidation compounds, particularly conjugated trienes and carbonyl compounds (Urbančič et al., 2014). Changes of K_{232} and K_{268} affected by OWF and POF are presented in Table 1. Regardless of the frying method used, K_{232} and K_{268} increased gradually with the frying days. It could be noticed that compared to the oil used for POF, the oil subjected to OWF displayed significant (p<0.05) smaller values of K_{232} and K_{268} on each day of frying. These results indicated that OWF mitigated the rate of oil oxidative alterations, while POF made oil suffer greater oxidative degradation. This was precisely because food scraps in the oil-water mixed fryer, primarily loose particles of the breading materials, continuously sank to water without accumulating in the oil from the very beginning to the very end of frying. Whereas as for POF, food scraps fell into the oil, accumulated at the bottom of the fryer and were fried continuously and repeatedly, which hastened the oxidative degradation of the oil (Rani et al., 2010; Lazarick et al., 2014).

It was found that the changes in K_{232} and K_{268} values were rapid during the first four days in either case of frying, indicating that a large amount of primary and secondary oxidation products were formed. However, K_{232} and K_{268} showed small increments in the last two days, which was related to the equilibrium that was established between the rate of formation of conjugated dienes and carbonyl compounds and the rate at which these compounds were transformed into oligomers and polymers (Abdulkarim et al., 2007; Koh et al., 2011).

Anisidine value

Primary oxidation reactions between oxygen and unsaturated fatty acids produce a lot of hydroperoxides. Due to their high instability at frying temperatures, hydroperoxides do not accumulate

Table 1. Changes in specific extinction coefficients (K_{232} and K_{268}) of soybean oil during oil-water mixed frying (OWF) and pure-oil frying (POF).

Frying time (days)	K_{232}		K_{268}	
	OWF	POF	OWF	POF
0	1.63 ± 0.08^{g}	1.63 ± 0.08^{g}	0.38 ± 0.05^{f}	0.38 ± 0.05^{f}
1	3.61 ± 0.11^{fB}	4.98 ± 0.11^{fA}	1.21 ± 0.07^{eB}	1.58 ± 0.12^{eA}
2	5.48 ± 0.17^{eB}	7.62 ± 0.09^{eA}	1.69 ± 0.14^{dB}	2.42 ± 0.07^{dA}
3	6.82 ± 0.08^{dB}	9.38 ± 0.09^{dA}	2.07 ± 0.06^{cB}	3.04 ± 0.04^{cA}
4	7.18 ± 0.14^{cB}	10.34 ± 0.12^{cA}	2.25 ± 0.07^{bB}	3.31 ± 0.14^{bA}
5	7.87 ± 0.12^{bB}	11.05 ± 0.06^{bA}	2.37 ± 0.06^{abB}	3.57 ± 0.10^{aA}
6	8.19 ± 0.21^{aB}	11.55 ± 0.12^{aA}	2.41 ± 0.09^{aB}	3.70 ± 0.07^{aA}

Results were expressed as Mean ± SD (n = 3). The different lowercase (for column) or uppercase letters (for row) indicate significant difference between different frying days or frying methods (p<0.05).

and spontaneously thermal decompose into various secondary oxidation products, including aldehydes and carbonyl compounds (Shyu et al., 1998; Kiran et al., 2015). AnV determines the content of aldehydes (principally 2-alkenals and 2,4-alkadienals) present in oil. Results shown in Table 2 revealed that there was a consistent and significant ($p<0.05$) increase in AnV in the case of OWF and POF over six days, from 0.41 in the fresh oil to 56.58 and 88.10 at the end of the frying process, respectively. When the two frying methods were compared, AnV of OWF was lower on each day, with significant differences ($p<0.05$) in the last four days, implying a clear reduction of the rate of secondary oxidation.

Carbonyl value

Carbonyl compounds are the most prominent and abundant secondary oxidation products from the degradation of hydroperoxides (Farhoosh & Moosavi, 2006). These compounds are mainly responsible for producing rancid and undesirable flavors and reducing the nutritional value of fried foods (Farhoosh & Tavassoli-Kafrani, 2011). The CV was found to linearly increase from 5.72 to 38.87 and 54.47, respectively for OWF and POF for 0–6 days (Table 2). The linear equations calculated from the linear relationship between CV and frying time were: OWF, $y = 5.42x + 4.51$, $R^2 = 0.982$; POF, $y = 8.61x + 4.22$, $R^2 = 0.991$ (y: CV, x: frying time). The slope of the linear equation was considered to be a measure of the rate of CV increase during the frying process. As expected, the lower slope was observed in the case of OWF, which confirmed that OWF retarded the formation of secondary oxidation products and decreased the intensity of oxidative reactions of oil during the six days by automatic filtration.

Free fatty acids

FFA result mainly from hydrolysis of triglycerides and partly from cleavage and oxidation of fatty acid double bonds (Aladedunye & Przybylski, 2014). Results shown in Table 2 revealed that FFA increased significantly ($p<0.05$) with the prolongation of frying days. In the case of POF, the hydrolysis was triggered by water vapor escaping from the chicken chops being fried. With regard to OWF, water from oil-water interface in the fryer also accelerated the hydrolytic degradation. Thus, the FFA in the case of OWF presented a higher degree of increase, revealing that OWF could not decrease the rate of oil hydrolysis.

Nevertheless, FFA may probably not a suitable index for monitoring the degree of frying oil degradation, because part of the fatty acids formed during frying are lost through vaporization and neutralization by the components of the food being fried (Man et al., 1999; Weisshaar, 2014). Furthermore, oxidation and polymerization are more prevalent than hydrolysis during frying, and generally only small amounts of FFA are formed and poorly correlated with the quality of fried products (Farhoosh & Tavassoli-Kafrani, 2011; Aladedunye & Przybylski, 2014). Therefore, FFA determination is dispensable to assess frying oil deterioration.

Viscosity

The increase in viscosity of frying oil enhances the formation of oxidative and polymeric compounds and gives rise to more oil absorbed by food (Dana & Saguy, 2006; Rossi et al., 2009). Viscosity of oil of different frying methods and various frying days

Table 2. Changes in anisidine value (AnV), carbonyl value (CV) and free fatty acids (FFA) of soybean oil during oil-water mixed frying (OWF) and pure-oil frying (POF).

Days of frying	AnV		CV (μmol g^{-1})		FFA (g 100g^{-1})	
	OWF	POF	OWF	POF	OWF	POF
0	0.41 ± 0.02^{g}	0.41 ± 0.02^{g}	5.72 ± 0.88^{g}	5.72 ± 0.88^{g}	0.08 ± 0.01^{g}	0.08 ± 0.01^{g}
1	14.16 ± 1.91^{f}	15.94 ± 1.66^{f}	10.46 ± 2.59^{f}	12.38 ± 2.56^{f}	0.26 ± 0.02^{fA}	0.22 ± 0.00^{fB}
2	31.25 ± 0.63^{e}	35.10 ± 2.67^{e}	14.87 ± 2.12^{eB}	19.49 ± 1.86^{eA}	0.38 ± 0.02^{eA}	0.33 ± 0.01^{eB}
3	40.27 ± 2.41^{dB}	58.57 ± 1.94^{dA}	19.44 ± 0.61^{dB}	29.07 ± 3.40^{dA}	0.51 ± 0.03^{dA}	0.44 ± 0.03^{dB}
4	45.76 ± 1.04^{cB}	70.87 ± 2.63^{cA}	23.95 ± 1.64^{cB}	39.29 ± 3.85^{cA}	0.61 ± 0.01^{cA}	0.53 ± 0.03^{cB}
5	52.17 ± 1.24^{bB}	78.57 ± 0.56^{bA}	32.08 ± 3.32^{bB}	49.85 ± 1.80^{bA}	0.69 ± 0.02^{bA}	0.63 ± 0.01^{bB}
6	56.58 ± 1.02^{aB}	88.10 ± 2.27^{aA}	38.87 ± 1.25^{aB}	54.47 ± 2.81^{aA}	0.85 ± 0.02^{aA}	0.77 ± 0.02^{aB}

Results were expressed as Mean ± SD (n = 3). The different lowercase (for column) or uppercase letters (for row) indicate significant difference between different frying days or frying methods ($p<0.05$).

Table 3. Changes in viscosity and color (CIE L* and b* values) of soybean oil during oil-water mixed frying (OWF) and pure-oil frying (POF).

Days of frying	Viscosity (mPa.s)		CIE L*		CIE b*	
	OWF	POF	OWF	POF	OWF	POF
0	50.07 ± 0.93^{f}	50.07 ± 0.93^{g}	77.01 ± 0.45^{a}	77.01 ± 0.45^{a}	7.18 ± 0.27^{g}	7.18 ± 0.27^{g}
1	52.16 ± 1.19^{fB}	55.43 ± 0.39^{fA}	75.25 ± 0.59^{b}	74.83 ± 0.66^{b}	14.63 ± 1.01^{fB}	16.88 ± 0.25^{fA}
2	54.79 ± 1.45^{eB}	59.03 ± 1.27^{eA}	74.13 ± 0.28^{bA}	73.00 ± 0.46^{cB}	16.41 ± 0.66^{eB}	18.95 ± 0.81^{eA}
3	57.39 ± 2.07^{dB}	64.27 ± 1.00^{dA}	71.73 ± 0.75^{c}	70.29 ± 1.26^{d}	18.01 ± 0.90^{dB}	21.58 ± 1.23^{dA}
4	60.79 ± 1.02^{cB}	70.60 ± 3.26^{cA}	70.08 ± 0.87^{dA}	66.34 ± 0.93^{eB}	20.41 ± 0.37^{cB}	24.35 ± 0.76^{cA}
5	65.41 ± 0.60^{bB}	77.19 ± 2.78^{bA}	67.88 ± 0.34^{eA}	63.83 ± 0.53^{fB}	21.75 ± 0.53^{bB}	27.56 ± 1.14^{bA}
6	68.59 ± 2.10^{aB}	86.80 ± 2.47^{aA}	66.61 ± 1.06^{fA}	62.34 ± 0.52^{gB}	22.97 ± 0.31^{aB}	31.29 ± 0.20^{aA}

Results were expressed as Mean ± SD (n = 3).The different lowercase (for column) or uppercase letters (for row) indicate significant difference between different frying days or frying methods ($p<0.05$).

are shown in Table 3. Consistent with previously published results (Rossi et al., 2009; Kalogianni et al., 2011), the oil experienced a linear increase in viscosity from the beginning through the sixth day of frying with high correlation coefficients ($R^2>0.97$), regardless of the type of frying methods (y: viscosity, x: frying time. OWF, $y = 3.15x + 49.02$, $R^2 = 0.983$; POF, $y = 5.90x + 48.49$, $R^2 = 0.976$). The increase in viscosity was strongly attributed to accumulation of the degradation products in oil, especially polymerization reactions products with higher molecular weight (Shyu et al., 1998; Rani et al., 2010). As reflected in the larger slope of the linear equation, the rate of increase of viscosity in the case of POF was considerably faster compared to OWF. Therefore, there was higher deteriorative effect of polymerization on the oil subjected to POF, which was because in the conventional fryer, contamination from deposited and charred food scraps accelerated the oil degradation (Orthoefe, 1988; Lazarick et al., 2014).

CIE color values

Change in color, especially darkening, is widely used to rapidly estimate the extent deterioration and the quality of used oil. The deterioration of CIE color values (L* and b* values) are shown in Table 3. A linear decrease for L* with increasing frying days was noted (y: CIE L*, x: frying time. OWF, $y = -1.79x + 77.17$, $R^2 = 0.993$; POF, $y = -2.60x + 77.45$, $R^2 = 0.986$), with the same trend also reported in other studies (Srivastava & Semwal, 2015). The darkening happened because of the presence of nonvolatile degradation products, such as polymers and oxidized triglycerides (Xu, 2003; Serjouie et al., 2010). The browning products of Maillard reaction from the interactions of ingredients and food nutrients also contributed to the darkening. Particularly, oil darkening might also be caused by the caramelized scorched food bits (Maskan, 2003). Therefore, OWF presented a lower rate of decrease in L* during the six days by filtering food scraps off continuously. As with the case of L* value, b* value was also significantly affected by the frying methods and frying time. The OWF increased b* value to 22.97, while POF gave a b* value of 31.29 after six days of frying. The increase in yellowness was related to the polymer formation of unsaturated carbonyl compounds and non-polar compounds of food stuff solubilized in the oil (Srivastava & Semwal, 2015).

3.2 Effects of frying methods on quality characteristics of fried chicken chops

Fat content

Table 4 shows fat content of fried chicken chops as a function of frying method and time. In previously published studies (Koh et al., 2011; Debnath et al., 2012; Mishra & Sharma, 2014), it was noted that the frying time had remarkable influence on oil content of fried products. This was also observed in the present study, where oil content showed significant ($p<0.05$) increment in the last day and in the last three days in the case of OWF and POF, respectively. The surfactant theory of frying that addressed how changing oil chemistry and food quality were interrelated might explain this observation (Blumenthal, 1991; Stier, 2013). As frying time increased and oil degraded, degradation products accumulated in the oil. Many of degradation products were polar compounds and acted as surfactants that could reduce the initially high surface tension at the oil-food interface. This consequently resulted in increasing contact between the chop and oil and excessive oil pickup by the chop. In addition, the increase in viscosity of oil with extended frying time was associated with the greater oil absorption by the chop (Dana & Saguy, 2006; Al-Khusaibi et al., 2012). The oil with higher viscosity caused a slow oil release from the chop into the oil surrounding and a greater oil retention on the surface of chop (Mellema, 2003). As a result, the drainage of oil from the chop decreased when the chop was removed from the fryer, thereby increasing the quantity of oil absorbed by the chop. For the two frying methods, it should be noted that the increase in oil content was more prominent in the case of POF after six days, with 58.13% of increase, which was due to the greater oil degradation of POF.

Acrylamide

Acrylamide is formed in a wide range of fried foods rich in starch and is classified as a “probable human carcinogen” (International Agency for Research on Cancer, 1994). In addition, acrylamide has the potential to cause a spectrum of toxic effects, such as neurotoxic and genotoxic effects (Liu et al., 2015). During frying, acrylamide is mainly produced by the Maillard reaction of reducing sugar with asparagines. Moreover, oxidative degradation of frying oil has been proposed as another pathway of acrylamide formation, with acrylic acid as a direct precursor that is formed by way of acrolein, by oxidation of glycerol in oil (Demirok & Kolsarıcı, 2014; Urbančič et al., 2014; Liu et al., 2015). The acrylamide concentrations in the fried chops were gradually increased during the frying process (Table 4), which was because the increased oxidation products of frying oil, as discussed previously, generated acrylamide formation. The final concentrations of acrylamide after six frying days were 1.41 and 1.82 $\mu g\ g^{-1}$ for OWF and POF, respectively. OWF significantly ($p<0.05$) reduced the acrylamide content. The significantly smaller ($p<0.05$) change in acrylamide content in the case of OWF than POF was due to the smaller change in the content of oxidation products in oil. Therefore, OWF could be proposed as an effective method to product healthier and safer chicken chops by retarding oil oxidative degradation.

Sensory properties

The basic aim of OWF performed to mitigate oil deterioration should be to maintain the sensory properties of fried products desired by consumers. Results concerning sensory evaluation for the chicken chops are summarized in Table 5. On the first day, regarding color, odor, flavor, texture and overall acceptability, sensory scores were 8.50, 8.41, 8.32, 8.41 and 8.36 for chops produced by OWF and 8.46, 8.35, 8.34, 8.46 and 8.33 for chops made by POF, respectively. These results showed that chops produced by OWF were graded with similar scores in terms of all sensory attributes evaluated when compared to chops made by POF on the first day, which meant OWF maintained the desirable sensory properties of the products.

While as frying time increased, effects of the frying time and methods on color attribute were noted. The color of fried products

Table 4. Oil content and acrylamide concentration of chicken chops after oil-water mixed frying (OWF) and pure-oil frying (POF).

Frying time (days)	Oil content (g 100g^{-1}, w.b.)		Acrylamide (μg g^{-1})	
	OWF	POF	OWF	POF
1	10.38 ± 0.71^{c}	10.35 ± 0.79^{d}	0.56 ± 0.04^{e}	0.58 ± 0.03^{e}
2	10.33 ± 0.57^{c}	10.87 ± 0.68^{d}	0.68 ± 0.10^{de}	0.73 ± 0.05^{de}
3	10.66 ± 0.45^{c}	11.81 ± 0.76^{cd}	0.77 ± 0.08^{cd}	0.84 ± 0.08^{d}
4	11.27 ± 0.22^{bcB}	13.04 ± 0.93^{cA}	0.91 ± 0.18^{c}	1.13 ± 0.11^{c}
5	11.97 ± 0.76^{abB}	14.52 ± 0.52^{bA}	1.18 ± 0.07^{bB}	1.45 ± 0.07^{bA}
6	12.86 ± 0.60^{aB}	16.47 ± 1.08^{aA}	1.41 ± 0.11^{aB}	1.82 ± 0.12^{aA}

Results were expressed as Mean ± SD (n = 3).The different lowercase (for column) or uppercase letters (for row) indicate significant difference between different frying days or frying methods ($p<0.05$).

Table 5. Sensory attributes scores of chicken chops after oil-water mixed frying (OWF) and pure-oil frying (POF).

Time (days)	Color		Odor		Flavor		Texture		Overall acceptability	
	OWF	POF	OWF	POF	OWF	POF	OWF	POF	OWF	POF
1	8.50 ± 0.17^{a}	8.46 ± 0.11^{a}	8.41 ± 0.14^{a}	8.35 ± 0.20^{a}	8.32 ± 0.16^{a}	8.34 ± 0.25^{a}	8.41 ± 0.22	8.46 ± 0.26	8.36 ± 0.15^{a}	8.33 ± 0.14^{a}
2	8.21 ± 0.24^{ab}	7.93 ± 0.28^{b}	8.35 ± 0.16^{a}	8.22 ± 0.27^{ab}	8.15 ± 0.17^{a}	7.95 ± 0.16^{a}	8.23 ± 0.19	8.31 ± 0.20	8.07 ± 0.21^{ab}	7.97 ± 0.20^{a}
3	7.91 ± 0.34^{bcA}	7.24 ± 0.12^{cB}	8.12 ± 0.24^{a}	7.96 ± 0.22^{b}	7.77 ± 0.28^{b}	7.46 ± 0.27^{b}	8.31 ± 0.32	8.40 ± 0.38	7.87 ± 0.10^{bA}	7.50 ± 0.19^{bB}
4	7.77 ± 0.28^{cdA}	6.70 ± 0.16^{dB}	7.72 ± 0.25^{b}	7.54 ± 0.12^{c}	7.45 ± 0.12^{cA}	6.70 ± 0.24^{cB}	8.17 ± 0.17	8.30 ± 0.30	7.53 ± 0.20^{cA}	6.86 ± 0.25^{cB}
5	7.56 ± 0.07^{cdA}	6.03 ± 0.32^{eB}	7.54 ± 0.19^{cbA}	7.11 ± 0.17^{dB}	7.34 ± 0.08^{cdA}	6.19 ± 0.36^{dB}	8.28 ± 0.20	8.22 ± 0.28	7.27 ± 0.15^{cdA}	6.11 ± 0.29^{dB}
6	7.41 ± 0.18^{dA}	5.05 ± 0.41^{fB}	7.28 ± 0.22^{cA}	6.56 ± 0.23^{eB}	7.05 ± 0.22^{dA}	5.52 ± 0.24^{eB}	8.33 ± 0.31	8.18 ± 0.31	7.07 ± 0.19^{dA}	5.39 ± 0.30^{eB}

Results were expressed as Mean ± SD (n = 3).The different lowercase (for column) or uppercase letters (for row) indicate significant difference between different frying days or frying methods ($p<0.05$).

is one of the most eminent quality characteristics. Color score was gradually decreased with frying time. This observation could be explained by the fact that as frying progressed, more surfactant compounds were formed and caused a reduction in the food-oil interfacial tension. The contact between chop and oil increased and the heat transfer to the surface of chop increased, and consequently resulting in excessive darkening of the surface (Blumenthal, 1991). As regards the impact of frying methods, from the third day onwards, the chops made by OWF had significant higher ($p<0.05$) scores compared to conventional fried chops, which was due to the less changes in quality of the oil subjected to OWF during six days as discussed in previous sections. Sensory evaluation showed that frying time and method also had effect on odor and flavor attributes of the products. The odor and flavor scores of oil-water mixed fried chops were around 8.41 and 8.32 respectively at the first frying day which decreased to 7.28 and 7.05 at the sixth day. The corresponding values for conventional fried chops were lower, viz., 8.35 and 8.34 at the first day, 6.56 and 5.52 at the sixth day, respectively. The odor and flavor differences between two frying methods perceived by panelists were likely the result of the different degree of oil deterioration of the two methods.

Other than color, odor and flavor, there was no significant difference ($p>0.05$) in texture between the frying methods and between the days of frying for each method. With regard to overall acceptability, from the first day to the sixth day, the scores decreased in both case of OWF and POF, with POF showing the greater decrease. Based on these results, OWF could be suggested as a viable alternative to POF to produce desirable fried meat products.

4 Conclusions

In the case of OWF, soybean oil showed less changes in all quality parameters studied K_{232} and K_{268}, AnV, CV, viscosity, CIE L* and CIE b* during the six consecutive frying days, expect FFA. These results demonstrated that OWF imparted lower oxidative and polymeric degradation on soybean oil in frying chicken chops as compared to POF. Meanwhile, OWF led to lower acrylamide formation in chicken chops during the six days, and smaller changes in fat content and sensory properties of chicken chops among the frying days were observed in the case of OWF.

Therefore, it can be concluded that oil-water mixed frying is a worthwhile alternative for retarding oil oxidative and polymeric deterioration and producing healthier, safer and higher quality fried meat products. However, it would be recommended for future researches on taking measures to mitigate the rate of oil hydrolysis during oil-water mixed frying.

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References

Abdulkarim, S. M., Long, K., Lai, O. M., Muhammad, S. K. S., & Ghazali, H. M. (2007). Frying quality and stability of high-oleic *Moringa oleifera* seed oil in comparison with other vegetable oils.

Food Chemistry, 105(4), 1382-1389. http://dx.doi.org/10.1016/j.foodchem.2007.05.013.

Aladedunye, F. (2015). Curbing thermo-oxidative degradation of frying oils: current knowledge and challenges. *European Journal of Lipid Science and Technology*, 117(11), 1867-1881. http://dx.doi.org/10.1002/ejlt.201500047.

Aladedunye, F., & Przybylski, R. (2013). Frying stability of high oleic sunflower oils as affected by composition of tocopherol isomers and linoleic acid content. *Food Chemistry*, 141(3), 2373-2378. http://dx.doi.org/10.1016/j.foodchem.2013.05.061. PMid:23870970.

Aladedunye, F., & Przybylski, R. (2014). Performance of palm olein and modified rapeseed, sunflower and soybean oils in intermittent deep-frying. *European Journal of Lipid Science and Technology*, 116(2), 144-152. http://dx.doi.org/10.1002/ejlt.201300284.

Al-Khusaibi, M., Gordon, M. H., Lovegrove, J. A., & Niranjan, K. (2012). Frying of potato chips in a blend of canola oil and palm olein: changes in levels of individual fatty acids and tocols. *International Journal of Food Science & Technology*, 47(8), 1701-1709. http://dx.doi.org/10.1111/j.1365-2621.2012.03024.x.

American Oil Chemists' Society – AOCS. (2004). *Official methods and recommended practices of AOCS* (5th ed.). Champaign: AOCS.

Association of Official Analytical Chemistry – AOAC. (2000). *Official methods of analysis of AOAC* (17th ed.). Washington: AOAC.

Blumenthal, M. M. (1991). A new look at the chemistry and physics of deep-fat frying. *Food Technology*, 45(2), 68-94.

Brühl, L. (2014). Fatty acid alterations in oils and fats during heating and frying. *European Journal of Lipid Science and Technology*, 116(6SI), 707-715. http://dx.doi.org/10.1002/ejlt.201300273.

Choe, E., & Min, D. B. (2007). Chemistry of deep-fat frying oils. *Journal of Food Science*, 72(5), R77-R86. http://dx.doi.org/10.1111/j.1750-3841.2007.00352.x. PMid:17995742.

Crosa, M. J., Skerl, V., Cadenazzi, M., Olazábal, L., Silva, R., Suburú, G., & Torres, M. (2014). Changes produced in oils during vacuum and traditional frying of potato chips. *Food Chemistry*, 146, 603-607. http://dx.doi.org/10.1016/j.foodchem.2013.08.132. PMid:24176387.

Dana, D., & Saguy, I. S. (2006). Review: mechanism of oil uptake during deep-fat frying and the surfactant effect-theory and myth. *Advances in Colloid and Interface Science*, 128-130, 267-272. http://dx.doi.org/10.1016/j.cis.2006.11.013. PMid:17196541.

Debnath, S., Rastogi, N. K., Gopala Krishna, A. G., & Lokesh, B. R. (2012). Effect of frying cycles on physical, chemical and heat transfer quality of rice bran oil during deep-fat frying of poori: an Indian traditional fried food. *Food and Bioproducts Processing*, 90(2), 249-256. http://dx.doi.org/10.1016/j.fbp.2011.05.001.

Demirok, E., & Kolsarıcı, N. (2014). Effect of green tea extract and microwave pre-cooking on the formation of acrylamide in fried chicken drumsticks and chicken wings. *Food Research International*, 63, 290-298. http://dx.doi.org/10.1016/j.foodres.2014.04.003.

Dobarganes, C., Márquez-Ruiz, G., & Velasco, J. (2000). Interactions between fat and food during deep-frying. *European Journal of Lipid Science and Technology*, 102(8-9), 521-528. http://dx.doi.org/10.1002/1438-9312(200009)102:8/9<521::AID-EJLT521>3.0.CO;2-A.

Endo, Y., Li, C. M., Tagiri-Endo, M., & Fujimoto, K. (2001). A modified method for the estimation of total carbonyl compounds in heated and frying oils using 2-propanol as a solvent. *Journal of the American Oil Chemists' Society*, 78(10), 1021-1024. http://dx.doi.org/10.1007/s11746-001-0381-1.

Farhoosh, R., & Moosavi, S. M. R. (2006). Determination of carbonyl value in rancid oils: a critical reconsideration. *Journal of Food Lipids*, 13(3), 298-305. http://dx.doi.org/10.1111/j.1745-4522.2006.00053.x.

Farhoosh, R., & Tavassoli-Kafrani, M. H. (2011). Simultaneous monitoring of the conventional qualitative indicators during frying of sunflower oil. *Food Chemistry*, 125(1), 209-213. http://dx.doi.org/10.1016/j.foodchem.2010.08.064. PMid:26434282.

International Agency for Research on Cancer – IARC. (1994). Acrylamide. In International Agency for Research on Cancer – IARC. *Monographs on the evaluation of carcinogenic risks to humans: some industrial chemicals* (Vol. 60, pp. 389-433). Lyon: IARC.

International Organization for Standardization – ISO. (1993). *Method 8586-1: sensory analysis: general guidance for the selection, training and monitoring of assessors. Part 1: selected Assessors*. Geneva: ISO.

International Organization for Standardization – ISO. (2011). *Method 3656: animal and vegetable fats and oils: determination of ultraviolet absorbance expressed as specific UV extinction*. Geneva: ISO.

Kalogianni, E. P., Karapantsios, T. D., & Miller, R. (2011). Effect of repeated frying on the viscosity, density and dynamic interfacial tension of palm and olive oil. *Journal of Food Engineering*, 105(1), 169-179. http://dx.doi.org/10.1016/j.jfoodeng.2011.02.021.

Kiran, C. R., Sasidharan, I., Kumar, D. S., & Sundaresan, A. (2015). Influence of natural and synthetic antioxidants on the degradation of Soybean oil at frying temperature. *Journal of Food Science and Technology*, 52(8), 5370-5375. http://dx.doi.org/10.1007/s13197-015-1774-7. PMid:26243968.

Koh, S. P., Arifin, N., Tan, C. P., Yusoff, M. S. A., Long, K., & Lai, O. M. (2011). Deep frying performance of enzymatically synthesized palm-based medium- and long-chain triacylglycerols (MLCT) oil blends. *Food and Bioprocess Technology*, 4(1), 124-135. http://dx.doi.org/10.1007/s11947-008-0138-y.

Lazarick, K., Aladedunye, F., & Przybylski, R. (2014). Effect of breading and battering ingredients on performance of frying oils. *European Journal of Lipid Science and Technology*, 116(6SI), 763-770. http://dx.doi.org/10.1002/ejlt.201300342.

Liu, Y., Wang, P., Chen, F., Yuan, Y., Zhu, Y., Yan, H., & Hu, X. (2015). Role of plant polyphenols in acrylamide formation and elimination. *Food Chemistry*, 186, 46-53. http://dx.doi.org/10.1016/j.foodchem.2015.03.122. PMid:25976790.

Man, Y. C., Liu, J. L., Jamilah, B., & Rahman, R. A. (1999). Quality changes of refined-bleached-deodorized (RBD) palm olein, soybean oil and their blends during deep-fat frying. *Journal of Food Lipids*, 6(3), 181-193. http://dx.doi.org/10.1111/j.1745-4522.1999.tb00142.x.

Maskan, M. (2003). Change in colour and rheological behaviour of sunflower seed oil during frying and after adsorbent treatment of used oil. *European Food Research and Technology*, 218(1), 20-25. http://dx.doi.org/10.1007/s00217-003-0807-z.

Mellema, M. (2003). Mechanism and reduction of fat uptake in deep-fat fried foods. *Trends in Food Science & Technology*, 14(9), 364-373. http://dx.doi.org/10.1016/S0924-2244(03)00050-5.

Mishra, R., & Sharma, H. K. (2014). Effect of frying conditions on the physico-chemical properties of rice bran oil and its blended oil. *Journal of Food Science and Technology*, 51(6), 1076-1084. http://dx.doi.org/10.1007/s13197-011-0602-y. PMid:24876639.

Moreira, R. G. (2014). Vacuum frying versus conventional frying: an overview. *European Journal of Lipid Science and Technology*, 116(6), 723-734. http://dx.doi.org/10.1002/ejlt.201300272.

Nehdi, I. (2011). Characteristics, chemical composition and utilisation of *Albizia julibrissin* seed oil. *Industrial Crops and Products*, 33(1), 30-34. http://dx.doi.org/10.1016/j.indcrop.2010.08.004.

Nelson, L. V. 3rd, Keener, K. M., Kaczay, K. R., Banerjee, P., Jensen, J. L., & Liceaga, A. (2013). Comparison of the FryLess 100 K Radiant

Fryer to oil immersion frying. *LWT - Food Science and Technology*, 53(2), 473-479. http://dx.doi.org/10.1016/j.lwt.2013.03.009.

Orthoefe, F. T. (1988). Care of food-service frying oils. *Journal of the American Oil Chemists' Society*, 65(9), 1417-1419.

Pawar, D. P., Boomathi, S., Hathwar, S. C., Rai, A. K., & Modi, V. K. (2013). Effect of conventional and pressure frying on lipids and fatty acid composition of fried chicken and oil. *Journal of Food Science and Technology*, 50(2), 381-386. http://dx.doi.org/10.1007/s13197-011-0331-2. PMid:24425931.

Rani, A. K. S., Reddy, S. Y., & Chetana, R. (2010). Quality changes in trans and trans free fats/oils and products during frying. *European Food Research and Technology*, 230(6), 803-811. http://dx.doi.org/10.1007/s00217-010-1225-7.

Rossi, M., Alamprese, C., Ratti, S., & Riva, M. (2009). Suitability of contact angle measurement as an index of overall oil degradation and oil uptake during frying. *Food Chemistry*, 112(2), 448-453. http://dx.doi.org/10.1016/j.foodchem.2008.05.101.

Serjouie, A., Ping Tan, C., Mirhossein, H., & Bin Che Ma, Y. (2010). Effect of vegetable-based oil blends on physicochemical properties of oils during deep-fat frying. *American Journal of Food Technology*, 5(5), 310-323. http://dx.doi.org/10.3923/ajft.2010.310.323.

Shyu, S., Hau, L., & Hwang, L. S. (1998). Effect of vacuum frying on the oxidative stability of oils. *Journal of the American Oil Chemists' Society*, 75(10), 1393-1398. http://dx.doi.org/10.1007/s11746-998-0188-3.

Srivastava, Y., & Semwal, A. D. (2015). A study on monitoring of frying performance and oxidative stability of virgin coconut oil (VCO) during continuous/prolonged deep fat frying process using chemical and FTIR spectroscopy. *Journal of Food Science and Technology*, 52(2), 984-991. http://dx.doi.org/10.1007/s13197-013-1078-8. PMid:25694709.

Stier, R. F. (2013). Ensuring the health and safety of fried foods. *European Journal of Lipid Science and Technology*, 115(8), 956-964. http://dx.doi.org/10.1002/ejlt.201300180.

Sun, Z. (2012). *The safety analysis and process optimization of fried prepared chicken products* (Master's thesis). Nanjing: Nanjing Agricultural University.

Teruel, M. D. R., Gordon, M., Linares, M. B., Garrido, M. D., Ahromrit, A., & Niranjan, K. (2015). A comparative study of the characteristics of french fries produced by deep fat frying and air frying. *Journal of Food Science*, 80(2), E349-E358. http://dx.doi.org/10.1111/1750-3841.12753. PMid:25619624.

Urbančič, S., Kolar, M. H., Dimitrijević, D., Demšar, L., & Vidrih, R. (2014). Stabilisation of sunflower oil and reduction of acrylamide formation of potato with rosemary extract during deep-fat frying. *LWT - Food Science and Technology*, 57(2), 671-678.

Wang, Y., Hui, T., Zhang, Y. W., Liu, B., Wang, F. L., Li, J. K., Cui, B. W., Guo, X. Y., & Peng, Z. Q. (2015). Effects of frying conditions on the formation of heterocyclic amines and trans fatty acids in grass carp (*Ctenopharyngodon idellus*). *Food Chemistry*, 167, 251-257. http://dx.doi.org/10.1016/j.foodchem.2014.06.109. PMid:25148986.

Weisshaar, R. (2014). Quality control of used deep-frying oils. *European Journal of Lipid Science and Technology*, 116(6), 716-722. http://dx.doi.org/10.1002/ejlt.201300269.

Xu, X. (2003). A chromametric method for the rapid assessment of deep frying oil quality. *Journal of the Science of Food and Agriculture*, 83(13), 1293-1296. http://dx.doi.org/10.1002/jsfa.1535.

Zhang, Q., Saleh, A. S. M., Chen, J., & Shen, Q. (2012). Chemical alterations taken place during deep-fat frying based on certain reaction products: a review. *Chemistry and Physics of Lipids*, 165(6), 662-681. http://dx.doi.org/10.1016/j.chemphyslip.2012.07.002. PMid:22800882.