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Quality characteristics of deep fat fried carrots depend on type of frying oil, frying temperature, and time of frying

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Abstract Carrots were deep fat fried with sunflower oil (SO), palm oil (PO), and a blend of palm and sunflower oils (PSO with PO:SO as 2:8 or 4:6) at different temperatures (180 and 190°C) and lengths of time (0.5 to 2.5 min). The quality of deep fat fried carrots was determined by the moisture and fat content, color, conjugated dienoic acid (CDA), hydroperoxide, *p*-anisidine value, and fatty acid composition. The moisture content of fried carrots decreased with increasing frying time, while the fat content increased. The CDA and *p*-anisidine values of carrots fried with SO were higher than those fried with PO because of greater unsaturated fatty acids content in SO. PSO was a better choice than SO or PO for deep fat frying carrots in the aspects of oxidative stability and ratio of unsaturated to saturated fatty acids. These results indicate that the quality of deep fat fried carrots depends on the type of oil and frying temperature used, as well as the length of time.

Keywords: deep fat frying, frying oil, carrots, blending oil, lipid oxidation

Introduction

Deep fat frying is a popular culinary method to prepare tasty food quickly (Mellema, 2003). The process of deep fat frying is soaking raw material in hot oil at temperature between 150 and 190°C, which many components were formed (Choe and Min, 2007). The deep fat fried food products tend to be attractive golden color and texture along with a typical flavor and taste so that extensively consumed worldwide (Al-Khusaibi et al., 2012; Bou et al., 2012; Rahimi et al., 2017). However, the high temperature for deep fat frying induces significant chemical changes to the oils (Casal et al., 2010).

During the deep fat frying of raw materials, the oil is subjected to high temperature in the presence of water and air, which leads to the formation of many unpleasant compounds (Aniolowska and Kita, 2016). The use of frying oil for a long time leads to produce off-flavor compounds, which change the stability, color, and nutritional quality of deep fat fried food products (Choe and Min, 2007). Initially, conjugated diene or conjugated triene, and hydroperoxides from the primary oxidation of free fatty acids are produced and alcohol, aldehydes, ketones, and cyclic compounds are formed as secondary products (Kowalski, 1989). These products can make worsen the sensory, functional, and nutritional quality of oils and fried products (Waghmare et al., 2018). Therefore, lipid oxidation is very important to determine the oil quality of deep fat fried food products (Choe and Min, 2007; Nor et al., 2008).

In addition, deep fat frying process can make high amounts of oil absorbed in fried products. For instance, the fat contents of potato chips, corn chips, and fried noodle usually contain 33, 30, and 14% of fat, respectively (Choe and Min, 2007). The fatty acid compositions contained to the deep fat fried products can therefore be considered as health aspects, especially the proportion of unsaturated and saturated fatty acids (Al-Khusaibi et al., 2012). For this matter, the choice of frying oil is very important when used for deep fat frying process (Matthäus, 2007).

Palm oil is widely used for deep fat frying process because it is easily available and provides a pleasant odor during frying (Mattähus, 2007; Mba et al., 2015). This oil is also characterized by higher smoke point and stronger resistance to oxidation than other commercial frying oils (Marco et al., 2007). Additionally, palm oil provides high productivity, low price, high oxidation stability, and good plasticity at room temperature. Leonardis and Macciola (2012) reported that minor components such as tocopherols, carotenoids, and sterols are present in palm oil (about 1 %). Palm oil has a distinct fatty acid and triacylglycerol profile which makes it suitable for many food products and it is the only vegetable oil with almost equal composition ratio of saturated and unsaturated fatty acids (Marco et al., 2007). It roughly contains 50% saturated fatty acids with 46.8% palmitic acid (C16:0) and unsaturated fatty acids with oleic acid (C18:1) at 37.6%. Therefore, the deep fat fried products with palm oil have possibly longer shelf life than the products fried with other vegetable oils (Panglogi et al., 2002). However, from a nutritional point of views, high amounts of saturated fatty acids can be concerned to be unhealthful because saturated fatty acids are critical for blood cholesterol leading to cardiovascular diseases (Matthäus, 2007). On the other hand, vegetable oils like sunflower oil, soybean oil, and canola oil containing high amounts of unsaturated fatty acids are

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known to be more health beneficial than palm oil (Matthäus, 2007).

In the frying foods industry, the change to vegetable oil has been a trend to improve the functional properties and nutritional quality of fried products (Mba et al., 2015). However, the drawback that high content of unsaturated fatty acids has disadvantage to low oxidative stability during frying must be considered (Al-Khusaibi et al., 2012). Blending two or more oils is another option to make new specific frying oil (Mba et al., 2015). The study of Farhoosh et al. (2009) showed the frying stability of canola oil blended with palm olein was improved compared with that of canola oil used for frying. In this study, carrots were deep fat fried with blending oil of palm oil and sunflower oil at different frying temperatures and lengths of time and their quality characteristics were investigated.

Materials and Methods

Materials

Raw carrots, palm oil, and sunflower oil were purchased from a local market (Jeju, Korea). Maltodextrin (Samyang Genex Co., Seoul, Korea) with dextrose equivalent (DE) value of 17-20 was used. Isooctane was purchased from Daejung Co. (Incheon, Korea). Ammonium thiocyanate, ferrous sulfate, *p*-anisidine, cumene hydroperoxide, and fatty acid methyl ester standard were purchased from Sigma-Aldrich Co. (St. Louis, MO, USA). Barium chloride was purchased from Merck (Darmstadt, Germany).

Deep fat frying carrots

Carrots were washed and sliced to 1.5 mm thickness using a slicer (TC-1410, Techon, Bucheon, Korea). The sliced carrots were blanched for 3 min and cooled down. The carrots were soaked with 40% maltodextrin for 2 h to remove moisture located inside of carrots and washed maltodextrin by running water. After removal of moisture, carrots were deep fat fried using an electric deep fat fryer (DS-100, Daeshin Co., Incheon, Korea). Palm oil (PO), sunflower oil (SO), and a blend of PO:SO at 2:8 or 4:6 (PSO 2:8, PSO 4:6) were used as frying oil, which ratio were determined by preliminary test. Carrots were deep fat fried at 180°C for 1, 1.5, 2 and 2.5 min or 190°C for 0.5, 1, 1.5 and 2 min. These frying conditions were determined after the preliminary test according to the study of Al-Khusaubu et al. (2012) and Matthäus (2006). The oil in deep fat fried carrots were extracted with Soxhlet apparatus following AOAC methods (2005) for lipid oxidation analysis.

Moisture and fat contents

Moisture and fat contents of deep fat fried carrots were determined according to AOAC methods (2005).

Color analysis

Color of the raw and deep fat fried carrots was measured using a colorimeter (CS-286, Konica Minolta Inc., Kyoto, Japan) after calibration with a white standard plate. The lightness (L*), redness (a*), and yellowness (b*) values of carrots were measured.

Fatty acids analysis

Fatty acids of deep fat fried carrots were derivatized to fatty acid methyl esters (FAME) using BF_3/MeOH (14% boron trifluoride) according to the AOCS methods (2004). The FAME was analyzed by gas chromatography (GC-17A, Shimadzu, Kyoto, Japan) with a SP-2560 column (100 mm×0.25 mm, 0.20 μm film thickness, Sigma-Aldrich) and flame ionization detector. The temperature of injection and detector was 260°C. The carrier gas was nitrogen at 1.0 mL/min. The oven temperature was programmed at 140°C for 5 min, increased to 200°C for 5 min, hold for 10 min, increased 240°C for 5 min, and hold for 20 min at 240°C. The fatty acids compositions were identified with the FAME standards (Sigma-Aldrich).

CDA value

Conjugated dienoic acids (CDA), which were primary oxidation products, were measured by AOCS (2004) and Bachari-Saleh et al. (2013). The extracted oil (0.1 g) from deep fat fried carrots were mixed with isooctane (25 mL) in a measuring flask and incubated at room temperature for 10 min. The absorbance was measured at 233 nm by UV/VIS spectrophotometer (OPTIZEN 2120 UV, Mecasys, Daejeon, Korea). The CDA was calculated as following:

$$\text{Conjugated dienoic acid (\%)} = \frac{0.84 \times A_s}{bc - K_0} \times 100$$

A_s: absorbance at 233 nm
K_0: absorptivity by acid, 0.03
b: cell length (cm)
c: concentration of sample in g L^{-1}.

Lipid hydroperoxide analysis

Lipid hydroperoxide contents were quantified from the oil extracted from deep fat fried carrots. Because the color of oil soluble carrot pigments in the extracted oils interrupted the analysis of peroxide value (AOCS, 2004), the method of lipid hydroperoxide analysis (Yi et al., 2016) was carried out as following. The extracted oil (10 mg) from deep fat fried carrots were mixed with 1.5 mL of isooctane:2-propanol (3:1, v/v). After vortex-mixing them for 1 min at three times, they were centrifuged at 2,000×g for 3 min. The supernatant (0.2 mL) was mixed with 2.8 mL of methanol:1-butanol (2:1, v/v). The thiocyanate/Fe^{2+} solution (10 μL) was added and vortex-mixed for 10 sec. The thiocyanate/Fe^{2+} solution was prepared by mixing equal volumes of 3.94 M thiocyanate solution with 0.072 M Fe^{2+} solution (supernatant of the mixture of one part of 0.144 M $FeSO_4$ and one part of 0.132 M $BaCl_2$ in 0.4 M HCl). The sample solutions were incubated for 20 min at room temperature. The absorbance at 510 nm was measured by UV/VIS spectrophotometer (Mecasys). The concentration of lipid hydroperoxides was calculated by a standard curve of cumene hydroperoxide.

p-Anisidine value

The *p*-anisidine value was determined by AOCS (2004). The extracted oil (0.5 g) from deep fat fried carrots were mixed with isooctane (25 mL) in a measuring flask. The oil solution (5 mL) was mixed with 0.25% *p*-anisidine solution (1 mL) and incubated at room temperature for 10 min. The absorbance at 350 nm was measured by UV/VIS spectrophotometer (Mecasys) and the *p*-anisidine value was calculated as the following equation.

$$p\text{-Anisidine value}=\frac{25\times(1.2A_s-A_b)}{W}$$

A_s: absorbance of the oil solution after reaction with the *p*-anisidine reagent

A_b: absorbance of the oil solution alone

W: weight of the sample (g)

Statistical analysis

The experiment results were determined by one-way analysis of variance (ANOVA) followed by Duncan's multiple range test using SPSS (PASW Statistics 18, SPSS Inc., Chicago, IL, USA). Significant differences were considered at $p<0.05$

Result and Discussion

Moisture and fat contents

The effects of frying oil, temperature, and time on the moisture and fat contents of deep fat fried carrots are shown in Tables 1 and 2. The moisture contents of deep fat fried carrots decreased after frying, while the fat contents increased. These moisture contents of deep fat fried carrots fried at 180°C ranged from 4.37 to 31.96% and at 190°C ranged from 3.18 to 63.22%. For deep fat fried carrots at 190°C, the moisture contents were significantly decreased with increasing frying time ($p<0.05$). The study of Shyu et al. (2005) indicated that the moisture contents of carrot slices were decreased as vacuum-frying time increased. The moisture contents of vacuum-fried carrots at 70°C for 5 and 30 min were 35.8 and 6.9%, respectively. When the frying temperature increased from 180 to 190°C for 2 min, the moisture contents of deep fat fried carrots except the carrots fried with SO decreased. For example, when deep fat fried carrots for 2 min with PO at 180 and 190°C, the moisture contents were 22.12 and 3.18%, respectively. Comparing with the type of frying oil, the moisture content of deep fat fried carrots with SO was the highest. Frying at 180°C for 2.5 min, the moisture content of fried carrots with SO and PO was 17.21 and 8.42%, respectively. When deep fat fried with SO at 190°C for 2 min, the moisture content was 29.56% and decreased to 15.13, 7.83, and 3.18% fried with PSO 2:8, PSO 4:6, and PO, respectively. Therefore, the moisture content in deep fat fried carrots was changed by frying time, temperature, and oil type.

Fat contents of deep fat fried carrots were significantly increased with increasing frying time ($p<0.05$, Tables 1 and 2). The fat contents of deep fat fried carrots frying with PSO 4:6 at 180°C for 2.5 min was the highest (42.82%) and SO for 1 min was the lowest (19.86%). Garayo and Moreira (2002) reported that the fat contents of vacuum-fried potato chips increased as frying time increased from 25 to 500 sec at 118, 132, and 144°C. When deep fat fried at 180 to 190°C, the fat contents were decreased or increased depending on the type of frying oil. The carrots fried with SO at 190°C contained lower fats than those at 180°C. The study of Kita et al. (2007) showed that the fat content of potato crisps fried with peanut oil decreased with high frying temperature at 190°C. Frying temperature is an important factor affecting the

Table 1. Moisture, fat contents, and color of deep fat fried carrots frying with sunflower oil (SO), palm oil (PO), and blend oil (PSO 2:8 or 4:6) at 180°C for 1, 1.5, 2 and 2.5 min

Frying		Moisture (%)	Fat (%)	Color		
Oil	Time (min)			L*	a*	b*
Raw carrot		94.12±0.30$^{a,1,2)}$	-	47.54±1.19^{abc}	25.72±2.29^{cd}	33.71±1.85^{abc}
SO	1	31.96±5.15^{b}	19.86±2.21^{h}	47.11±0.13^{abc}	30.54±0.33^{ab}	36.31±0.36^{a}
	1.5	18.37±1.40^{cde}	29.36±1.49^{ef}	48.01±1.73^{ab}	21.16±2.21^{defg}	28.90±6.98^{bc}
	2	21.98±1.68^{cd}	31.03±0.96^{de}	45.27±0.73^{bcd}	23.80±2.75^{cd}	35.66±1.63^{ab}
	2.5	17.21±6.26^{cde}	34.52±3.11^{bcd}	45.90±1.54^{abc}	23.03±0.58^{de}	34.50±1.13^{ab}
PSO 2:8	1	16.43±5.50^{cde}	35.97±2.38^{bc}	47.92±0.67^{ab}	27.87±0.73^{bc}	36.33±0.19^{a}
	1.5	13.41±5.65^{efg}	23.31±1.69^{gh}	48.70±1.52^{a}	17.00±1.18^{ghi}	35.56±1.85^{ab}
	2	17.71±3.71^{cde}	33.40±1.19^{cde}	46.10±0.91^{abc}	24.06±4.17^{cd}	32.30±1.27^{abc}
	2.5	5.78±0.77^{gh}	34.80±3.07^{bcd}	42.67±2.86^{de}	18.86±3.87^{efgh}	35.65±5.38^{ab}
PSO 4:6	1	14.01±2.13^{def}	34.67±1.42^{bcd}	46.71±3.90^{abc}	31.42±2.92^{ab}	33.84±7.38^{abc}
	1.5	13.93±2.18^{def}	36.36±0.73^{bc}	44.32±1.54^{cde}	33.18±1.89^{a}	29.97±2.33^{abc}
	2	10.33±2.77^{efgh}	37.12±1.01^{bc}	41.34±1.14^{ef}	22.10±2.08^{def}	35.53±4.70^{ab}
	2.5	4.37±5.85^{h}	42.82±2.11^{a}	37.57±1.53^{g}	13.83±1.95^{i}	21.94±4.54^{d}
PO	1	30.76±7.64^{b}	24.98±5.12^{g}	48.90±1.48^{a}	30.85±0.31^{ab}	35.56±0.45^{ab}
	1.5	23.25±2.77^{c}	26.29±2.64^{fg}	46.79±1.35^{abc}	27.95±6.06^{bc}	32.48±1.02^{abc}
	2	22.12±5.28^{cd}	29.62±5.01^{ef}	39.51±2.38^{fg}	18.11±2.06^{fghi}	31.94±1.19^{abc}
	2.5	8.42±6.89^{fgh}	39.04±2.14^{ab}	39.62±1.01^{fg}	16.23±1.10^{hi}	27.66±4.24^{cd}

[1)]Each value is mean±standard deviation.

[2)]Means with different letter in a column indicate significant difference ($p<0.05$) by Duncan's multiple range test.

Table 2. Moisture, fat contents, and color of deep fat fried carrots frying with sunflower oil (SO), palm oil (PO), and blend oil (PSO 2:8 or 4:6) at 190°C for 0.5, 1, 1.5, and 2 min

Frying		Moisture (%)	Fat (%)	Color		
Oil	Time (min)			L*	a*	b*
Raw carrot		94.12±0.30[a,1,2)]	-	47.54±1.19[abc]	25.72±2.29[cd]	33.71±1.85[abc]
SO	0.5	63.22±4.06[b]	19.91±1.66[gh]	50.14±1.34[abc]	22.79±3.89[bc]	34.29±2.96[abc]
	1	41.29±1.95[de]	24.97±1.95[defg]	46.84±0.79[bcd]	28.69±3.83[a]	34.17±1.86[abc]
	1.5	34.80±4.67[ef]	26.34±4.72[def]	46.15±1.05[cd]	27.91±3.67[ab]	34.95±1.09[abc]
	2	29.56±0.87[f]	29.51±7.35[de]	40.38±1.02[e]	26.06±0.99[ab]	32.01±3.31[bcd]
PSO 2:8	0.5	31.45±6.29[f]	25.36±1.96[def]	51.81±0.55[a]	29.42±1.86[a]	38.06±1.67[ab]
	1	29.70±1.23[f]	29.73±3.37[de]	48.88±2.63[abcd]	29.52±2.66[a]	36.24±3.56[abc]
	1.5	19.33±3.32[gh]	40.75±3.02[a]	45.90±2.40[d]	28.08±2.32[a]	35.89±2.93[abc]
	2	15.13±3.77[hi]	38.83±1.47[ab]	39.89±1.34[e]	26.40±1.72[ab]	31.95±0.63[bcd]
PSO 4:6	0.5	45.14±8.03[cd]	19.11±0.90[h]	49.78±1.09[abcd]	25.86±3.67[ab]	36.71±0.97[abc]
	1	30.09±1.27[fg]	24.67±1.23[efg]	47.88±0.80[abcd]	28.45±3.24[a]	39.76±4.28[a]
	1.5	21.66±1.77[h]	30.31±1.97[cd]	47.85±1.20[abcd]	27.21±0.24[ab]	37.24±3.13[abc]
	2	7.83±5.00[ij]	25.84±3.81[efg]	40.54±2.70[e]	18.49±1.29[cd]	30.16±6.00[cd]
PO	0.5	50.41±7.42[c]	22.25±3.59[fgh]	50.53±.59[ab]	28.04±2.92[a]	37.83±1.82[ab]
	1	28.83±0.14[f]	29.23±2.81[de]	48.49±1.57[abcd]	24.31±2.90[ab]	36.75±1.76[abc]
	1.5	4.69±1.49[j]	37.22±3.23[ab]	47.31±3.55[bcd]	25.17±1.11[ab]	37.62±4.59[ab]
	2	3.18±2.03[j]	34.85±2.19[bc]	37.25±5.46[e]	17.09±3.39[d]	24.51±6.26[d]

[1)]Each value is mean±standard deviation.
[2)]Means with different letter in a column indicate significant difference (p<0.05) by Duncan's multiple range test.

Table 3. Fatty acid compositions of deep fat fried carrots frying with sunflower oil (SO), palm oil (PO), and blend oil (PSO 2:8 or 4:6) at 180°C for 1, 1.5, 2 and 2.5 min

Frying		Fatty acid compositions (%)					
Oil	Time (min)	16:0	18:0	18:1	18:2	Saturated	Unsaturated
SO	1	6.76±0.03[f]	3.33±0.02[e]	30.11±0.15[e]	59.80±0.12[a]	10.09±0.05[f]	89.91±0.05[a]
	1.5	6.73±0.12[f]	3.36±0.05[e]	30.27±0.15[e]	59.64±0.30[a]	10.09±0.15[f]	89.91±0.15[a]
	2	6.72±0.03[f]	3.37±0.04[e]	29.92±0.25[e]	59.99±0.27[a]	10.09±0.03[f]	89.91±0.03[a]
	2.5	6.75±0.05[f]	3.39±0.04[e]	30.12±0.34[e]	59.73±0.39[a]	10.14±0.05[f]	89.86±0.05[a]
PSO 2:8	1	13.55±0.11[e]	4.13±0.14[b]	32.15±0.48[d]	50.13±0.43[b]	17.73±0.17[e]	85.27±0.17[b]
	1.5	13.62±0.09[e]	4.05±0.27[bc]	32.93±0.04[c]	49.34±0.30[cd]	17.73±0.33[e]	82.27±0.33[b]
	2	14.32±0.31[d]	4.08±0.07[bc]	32.78±0.12[c]	48.82±0.30[d]	18.39±0.26[d]	81.61±0.26[c]
	2.5	14.11±0.25[d]	4.06±0.06[bc]	31.99±0.11[d]	49.83±0.30[bc]	18.18±0.29[d]	81.82±0.29[c]
PSO 4:6	1	21.94±0.24[c]	3.93±0.05[cd]	33.79±0.73[b]	40.34±0.58[e]	25.88±0.25[c]	74.12±0.25[d]
	1.5	22.07±0.08[c]	3.82±0.04[d]	33.73±0.59[b]	40.37±0.58[e]	25.89±0.11[c]	74.11±0.11[d]
	2	22.24±0.04[c]	3.82±0.05[d]	33.55±0.35[b]	40.38±0.33[e]	26.06±0.06[c]	73.94±0.06[d]
	2.5	22.18±0.16[c]	3.81±0.08[d]	33.79±0.28[b]	40.23±0.36[e]	25.99±0.12[c]	74.01±0.12[d]
PO	1	47.46±0.33[a]	4.74±0.11[a]	38.44±0.32[a]	9.36±0.66[f]	52.20±0.41[ab]	47.80±0.41[f]
	1.5	47.19±0.41[ab]	4.69±0.07[a]	38.53±0.05[a]	9.59±0.50[f]	51.89±0.46[a]	48.11±0.46[ef]
	2	47.30±0.46[ab]	4.77±0.05[a]	38.56±0.38[a]	9.38±0.29[f]	52.07±0.45[a]	47.93±0.45[f]
	2.5	46.91±0.17[b]	4.70±0.03[a]	38.51±0.33[a]	9.88±0.24[f]	51.61±0.17[b]	48.39±0.17[e]

[1)]Each value is mean±standard deviation.
[2)]Means with different letter in a column indicate significant difference (p<0.05) by Duncan's multiple range test.

oil absorption which directly impacts on the crispiness of fried products. Generally, the high temperature during frying process leads to fast development of hard surface which is consequently favorable for fried products (Garayo and Moreira, 2002).

Color

Tables 1 and 2 show the changes in lightness (L*), redness (a*), and yellowness (b*) values of deep fat fried carrots. As the frying time increased, the L* value was significantly decreased (p<0.05). Similar results were observed that the L* values of the vacuum-fried carrots at 100°C for 5 to 30 min were significantly decreased (Shyu et al., 2005). The study of Teruel Mdel et al. (2015) indicated that the L* values of potato strips fried with sunflower oil at 180°C were decreased with the increase of frying time. The

Table 4. Fatty acids compositions of deep fat fried carrots frying with sunflower oil (SO), palm oil (PO), and blend oil (PSO 2:8 or 4:6) at 190°C for 0.5, 1, 1.5, and 2 min

Frying		Fatty acid compositions (%)					
Oil	Time (min)	16:0	18:0	18:1	18:2	Saturated	Unsaturated
SO	0.5	6.76±0.03[d]	3.33±0.02[d]	30.11±0.15[f]	59.80±0.12[a]	10.09±0.05[d]	89.91±0.05[a]
	1	6.73±0.12[d]	3.36±0.05[d]	30.27±0.15[f]	59.64±0.30[a]	10.09±0.15[d]	89.91±0.15[a]
	1.5	6.72±0.03[d]	3.37±0.04[d]	29.92±0.25[f]	59.99±0.27[a]	10.09±0.03[d]	89.91±0.03[a]
	2	6.75±0.05[d]	3.39±0.04[d]	30.12±0.34[f]	59.73±0.39[a]	10.14±0.05[d]	89.86±0.05[a]
PSO 2:8	0.5	14.36±0.08[c]	3.95±0.07[b]	31.94±0.29[de]	49.75±0.35[bc]	18.31±0.11[c]	81.69±0.11[bc]
	1	14.38±0.02[c]	3.86±0.05[bc]	32.69±0.27[cd]	49.07±0.27[c]	18.24±0.04[c]	81.76±0.04[b]
	1.5	14.32±0.13[c]	3.84±0.04[bc]	31.38±0.22[e]	50.46±0.12[b]	18.16±0.14[c]	81.84±0.14[c]
	2	14.06±0.13[c]	3.85±0.09[bc]	32.56±0.29[d]	49.58±0.41[c]	17.91±0.18[c]	82.09±0.18[b]
PSO 4:6	0.5	21.06±0.24[b]	3.92±0.10[b]	34.14±0.86[b]	40.89±0.66[e]	24.97±0.24[b]	75.03±0.24[d]
	1	21.01±0.49[b]	3.93±0.03[b]	34.05±0.85[b]	41.02±0.76[de]	24.93±0.47[b]	75.07±0.47[d]
	1.5	21.21±0.21[b]	3.75±0.14[c]	33.42±0.62[bc]	41.62±0.59[de]	24.96±0.34[b]	75.04±0.34[d]
	2	20.83±0.50[b]	3.88±0.09[b]	33.48±0.91[bc]	41.81±0.90[d]	24.71±0.45[b]	75.29±0.45[d]
PO	0.5	45.32±0.14[a]	4.61±0.02[a]	37.49±0.35[a]	12.58±0.48[f]	49.93±0.13[a]	50.07±0.13[e]
	1	45.52±0.38[a]	4.63±0.06[a]	37.75±0.04[a]	12.10±0.40[f]	50.15±0.44[a]	49.85±0.44[e]
	1.5	45.39±0.26[a]	4.66±0.06[a]	37.58±0.24[a]	12.11±0.13[f]	50.04±0.31[a]	49.96±0.31[e]
	2	45.68±0.21[a]	4.67±0.06[a]	37.57±0.11[a]	12.08±0.27[f]	50.35±0.17[a]	49.65±0.17[e]

[1)]Each value is mean±standard deviation.
[2)]Means with different letter in a column indicate significant difference (p<0.05) by Duncan's multiple range test.

loss of lightness was possibly caused by low moisture content in deep fat fried carrots (Shyu et al., 2005). Additionally, the L* values of deep fat fried carrots at 190°C were lower than those at 180°C. These results were similar to the study of Salehi (2018) observing the decrease of lightness in carrots fried at 190°C from 170°C with sunflower oil. The a* and b* values of deep fat fried carrots were generally decreased with increasing frying time. These reduction of color values was possibly related to the carotenoid contents in carrots, which were unstable at high temperature of frying (Shyu et al., 2005).

Fatty acid composition

Fatty acid composition of deep fat fried carrots frying with sunflower oil (SO), palm oil (PO), and blend oil (PSO 2:8 or 4:6) at 180°C for 1, 1.5, 2 and 2.5 min and 190°C for 0.5, 1, 1.5, 2 min are shown in Table 3 and 4. Palmitic (C16:0), stearic (C18:0), oleic (C18:1), and linoleic acid (C18:2) were major fatty acids in deep fat fried carrots. When considering the effects of frying time and temperature, the composition of fatty acids was not significantly different (p>0.05). Shyu et al. (2005) indicated that linoleic and linolenic acids in deep fat fried carrots were significantly decreased during the vacuum-frying of 8 to 48 h. After deep fat frying of potato chips with a blend of sunflower and palm oil for 240 min, the content of palmitic acid was increased and linolenic acid was decreased (Marco et al., 2007). The loss of unsaturated fatty acids was 38.8% when potato chips fried at 180°C for 70 h with soybean oil (Tyagi and Vasishtha, 1996). In the current study, the length of frying time was very short compared to those studies so that the fatty acids composition was not greatly changed.

The saturated fatty acids of deep fat fried carrots frying with PO was the highest (50%) and those with SO was lowest because of their indigenous fatty acids profiles. PO and SO contained 48 and 90% of unsaturated fatty acids, respectively. When blending with PO:SO as 2:8 and 4:6, the contents of unsaturated fatty acids were changed to 82 and 75%, respectively. Thus, a blend of PO and SO was a better option than PO only for deep fat frying carrots when considering a nutritional point of view (Matthäus, 2007).

Lipid oxidation

Lipid oxidation of deep fat fried carrots fried with different types of oil, frying temperatures, and time was compared by CDA values, hydroperoxide contents, and p-anisidine values. Fig. 1 shows CDA values of the extracted oil from deep fat fried carrots frying with SO, PO, PSO 2:8, and PSO 4:6 at 180°C for 1, 1.5, 2 and 2.5 min and 190°C for 0.5, 1, 1.5, 2 min. The initial CDA values of SO, PSO 2:8, PSO 4:6, and PO were 0.10, 0.08, 0.09, and 0.09%, respectively. After deep fat frying, the CDA values were increased. While the CDA value of deep fat fried carrots with PO at 180°C for 1.5 min was 0.12%, that of carrots with SO at 180°C for 2.5 min was 0.46%. Also, the CDA values of carrots fried with PSO 2:8 and PSO 4:6 were lowered compared to those fried with SO only. The more unsaturated fatty acids were present, the greater CDA showed because conjugated dienes are formed by the oxidation of polyunsaturated fatty acids (Kim et al., 2013). Furthermore, conjugated dienes are more stable than non-conjugated fatty acids during oxidation or frying processing (Chung et al., 2004). Kim et al. (2013) reported that soybean oil showed higher CDA value than lard because of high concentration of polyunsaturated fatty acids. Additionally, Abdulkarim et al. (2007) indicated that the low value of CDA in *moringa oleifera* seed oil meant the greatly stable to the oxidation. SO has low content of monounsaturated fatty acids and high content of polyunsaturated fatty acids

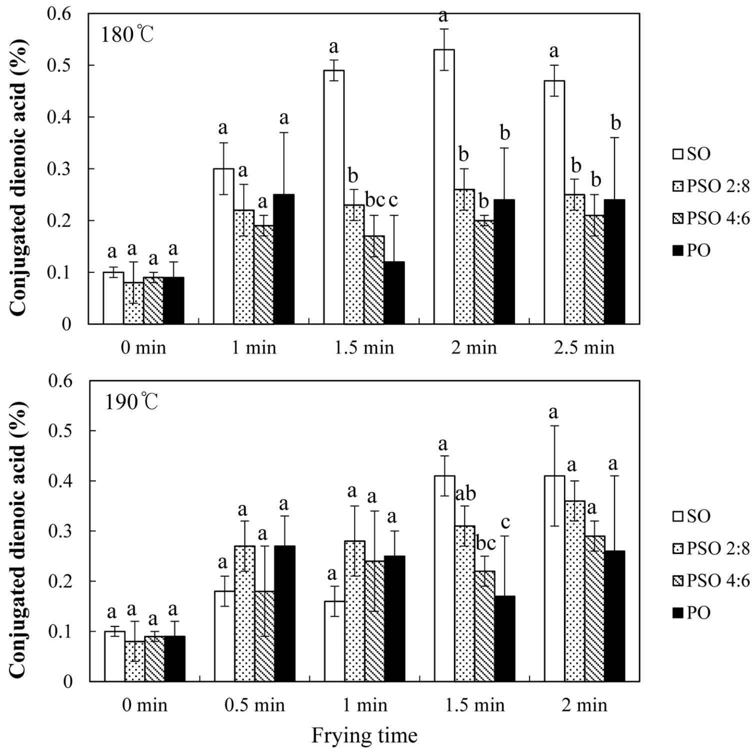

Fig 1. Conjugated diene acid (CDA) content of deep fat fried carrots frying with sunflower oil (SO), palm oil (PO), and blend oil (PSO 2:8 or 4:6) at 180°C for 1, 1.5, 2, and 2.5 min or 190°C for 0.5, 1, 1.5, and 2 min. Dissimilar small alphabets on the bar within frying time are significantly different at $p<0.05$.

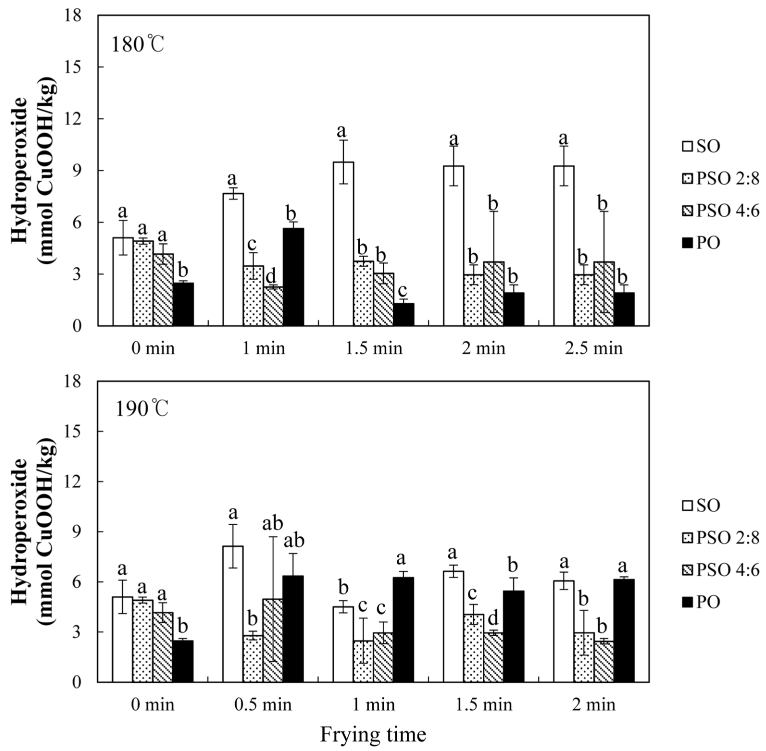

Fig 2. Lipid hydroperoxide content of deep fat fried carrots frying with sunflower oil (SO), palm oil (PO), and blend oil (PSO 2:8 or 4:6) at 180°C for 1, 1.5, 2, and 2.5 min or 190°C for 0.5, 1, 1.5, and 2 min. Dissimilar small alphabets on the bar within frying time are significantly different at $p<0.05$.

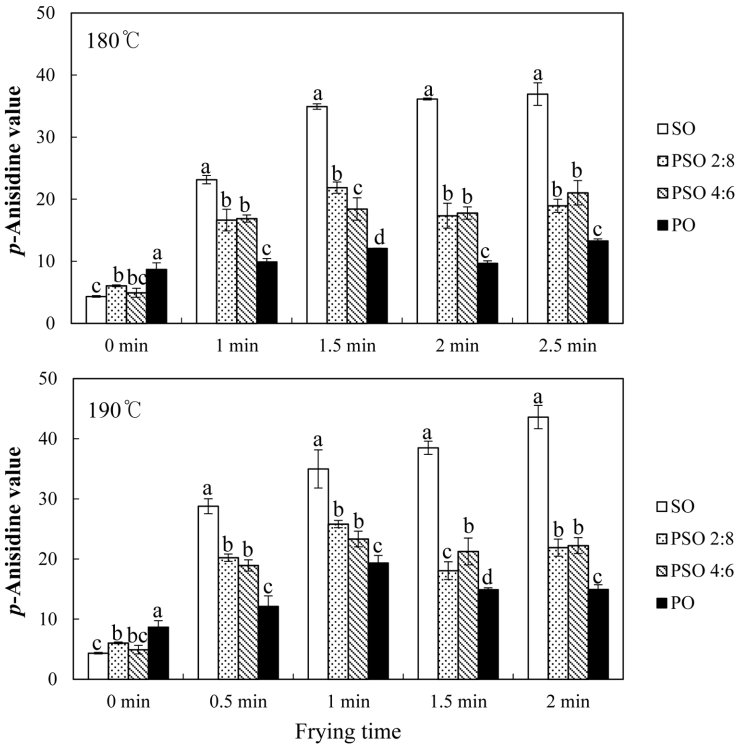

Fig 3. *p*-Anisidine value of deep fat fried carrots frying with sunflower oil (SO), palm oil (PO), and blend oil (PSO 2:8 or 4:6) at 180°C for 1, 1.5, 2, and 2.5 min or 190°C for 0.5, 1, 1.5, and 2 min. Dissimilar small alphabets on the bar within frying time are significantly different at $p<0.05$.

compared to other frying oils so high in the CDA values.

Figure 2 shows hydroperoxide contents of deep fat fried carrots frying with SO, PO, PSO 2:8, and PSO 4:6 at 180 and 190°C for different lengths of frying time. The hydroperoxide content of deep fat fried carrots with PO at 180°C for 1.5 min was the lowest (1.5 mmol CuOOH/kg). When carrots were vacuum fried, the hydroperoxide increased as frying time increased (Shyu et al., 2005). However, in the current study, the tendency of hydroperoxide contents were not significantly different with frying time within the same frying oil treatment. Mostly, the type of oil affected to the hydroperoxide contents of fried carrots. For example, hydroperoxide contents of deep fat fried carrots at 180°C with SO and PO for 1.5 min were 9.6 and 1.5 mmol CuOOH/kg, respectively. The oil that contains high amounts of unsaturated fatty acids is more quickly oxidized than less unsaturated oil (Choe and Min, 2007). Therefore, hydroperoxides in the carrots fried with SO were highly formed compared to those with PO.

The *p*-anisidine value of deep fat fried carrots frying with different types of oil, temperatures, and time lengths are shown in Fig. 3. The initial *p*-anisidine values of SO, PSO 2:8, PSO 4:6, and PO were 4.33, 6.05, 4.92, and 8.68, respectively. Although the *p*-anisidine value of PO was initially high, those of the deep fat fried carrots fried with PO were kept in low. When fried with SO at 190°C for 2 min, the *p*-anisidine value was the highest, 43.52. As similar as the results of hydroperoxide contents, the type of frying oil impacted on the oxidation of deep fat fried carrots. The production of secondary oxidative compounds in fried carrots was increased as the ratio of SO increased. Matthäus (2006) reported that *p*-anisidine values of French fries fried with vegetable oil containing high amounts of polyunsaturated fatty acids were higher than those fried with palm olein. The *p*-anisidine value of highly unsaturated soybean oil increased to 50% after 20 h of frying (Lee et al., 2002). Therefore, the oxidative stability of deep fat fried carrots was improved when a blend oil of PO and SO was used.

Conclusion

In this study, carrots were deep fat fried at different types of frying oil, frying temperature, and time of frying. Moisture contents and color values of deep fat fried carrots were decreased as frying time, temperatures, and SO ratio of frying oil increased. On the contrary, when frying time and PO ratio of frying oil were increased, the fat contents of fried carrots were increased. Fatty acid composition was not affected by frying temperature and time of frying. The amount of unsaturated fatty acids of deep fat fried carrots with SO was higher than those of other types of frying oils. When deep fat fried with a blend of PO and SO, high unsaturated fatty acids contents were observed in fried carrots compared to those fried with PO. Oxidative stability of deep fat fried carrots more depended on the type of frying oil than frying temperature and time. Compared to the carrots fried with SO, the lipid oxidation of carrots fried with PO was greatly delayed. The PO was the best option for the prevention of lipid oxidation during frying of carrots; however, for nutritional aspect, a blend of PO and SO (PSO 2:8, PSO 4:6) could be a good choice.

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References

Abdulkarim S, Long K, Lai O, Muhammad S, Ghazali H. Frying quality and stability of high-oleic *Moringa olifera* seed oil in comparison with other vegetable oils. Food Chem. 105: 1382-1389 (2007)

Al-Khusaibi M, Gordon M, Lovegrove J, Niranjan K. Frying of potato chips in a blend of canola oil and palm olein: changes in levels of individual fatty acids and tocols. Int. J. Food Sci. Technol. 47: 1701-1709 (2012)

Aniolowska M, Kita A. The effect of frying on glycidyl esters content in palm oil. Food Chem. 203: 95-103 (2016)

AOAC. Official Method of Analysis of AOAC Intl. 18th ed. Method 981.05. Association of Official Analytical Chemists, Arlington, VA, USA (2005)

AOCS. Official Methods and Recommended Practices. 5th ed. Method Cd 8b-90, Cd 18-90, Ch 2a-94, and Ti 1a-64. American Oil Chemists' Society, Champaign, IL, USA (2004)

Bachari-Saleh Z, Ezzatpanah H, Aminafshar M, Safafar H. The effect of refining process on the conjugated dienes in soybean oil. J. Agr. Sci. Technol. 15: 1185-1193 (2013)

Bou R, Navas J.A, Tres A, Codony R, Guardiola F. Quality assessment of frying fats and fried snacks during continuous deep fat frying at different large-scale producers. Food Control 27: 254-267 (2012)

Casal S, Malheiro R, Sendas A, Oliveira B. Olive oil stability under deep-frying conditions. Food Chem. Toxicol. 48: 2972-2979 (2010)

Choe E, Min DB. Chemistry of deep fat frying oils. J. Food Sci. 72: R77-R86 (2007)

Chung J, Lee J, Choe E. Oxidative stability of soybean and sesame oil mixture during frying of flour dough. J. Food Sci. 69: 574-578 (2004)

Farhoosh R, Kenari R, Poorazrang H. Frying stability of canola oil blended with palm olein, olive, and corn oils. J. Am. Oil Chem. Soc. 86: 71-76 (2009)

Garayo J, Moreira R. Vacuum frying of potato chips. J. Food Eng. 55: 181-191 (2002)

Kim T, Yeo J, Kim J, Kim M, and Lee J. Determination of the degree of oxidation in highly-oxidized lipids using profile changes of fatty acids. Food Chem. 138: 1792-1799 (2013)

Kita A, Lisinska G, Golubowska G. The effects of oils and frying temperatures on the texture and fat content of potato crisp. Food Chem. 102: 1-5 (2007)

Kowalski B. Determination of oxidative stability of edible vegetable oils by pressure differential scanning calorimetry. Thermochimica Acta. 156: 347-358 (1989)

Lee J, Lee S, Lee H, Park K, Choe E. Spinach (*Spinacia oleracea*) powder as a natural food-grade antioxidant in deep-fat-fried products. J. Agr. Food Chem. 50: 5664-5669 (2002)

Leonardis A, Macciola V. Heat-oxidation stability of palm oil blended with extra virgin olive oil. Food Chem. 135: 1769-1776 (2012)

Marco E, Savarese M, Cristina P, Ilaria B, Falco S, Sacci R. Frying performance of a sunflower/palm oil blend in comparison with pure palm oil. Eur. J. Lipid Sci. Technol. 109: 237-346 (2007)

Matthäus B. Utilization of high-oleic rapeseed oil for deep fat frying of French fries compared to other commonly used edible oils. Eur. J. Lipid Sci. Technol. 108: 200-211 (2006)

Matthäus B. Use of palm oil for frying in comparison with other high-stability oils. Eur. J. Lipid Sci. Technol. 109: 400-409 (2007)

Mba O, Dumont M, Ngadi M. Palm oil: Processing, characterization and utilization in the food industry – A review. Food Biosci. 10: 26-41 (2015)

Mellema M. Mechanism and reduction of fat uptake in deep fat fried foods. Trends Food. Sci. Tech. 14: 364-373 (2003)

Nor FM, Mohamed S, Idris NA, Ismail R. Antioxidative properties of *Pandanus amaryllifolius* leaf extracts in accelerated oxidation and deep frying studies. Food Chem. 110:319-327 (2008)

Panglogi P, Melton S.L, Collins J.L, Penfield M.P, Saxton A.M. Flavor and storage stability of potato chips fried in cottonseed and sunflower oils and palm olein/sunflower oil blends. J. Food Sci. 67: 97-103 (2002)

Rahimi J, Adewale P, Ngadi M, Agyare K. Changes in the textural and thermal properties of batter coated fried potato strips during post frying holing. Food Bioprod. Process. 102: 136-143 (2017)

Salehi F. Color changes kinetics during deep fat frying of carrots slice. Heat Mass Transfer. 54: 3421-3426 (2018)

Shyu S, Hau L, Hwang L. Effect of processing conditions on the quality of vacuum-fried carrot chips. J. Sci. Food. 85: 1903-1908 (2005)

Teruel Mdel R, Gordon M, Linares MB, Garrido MD, Ahromrit A, Niranjan K. A comparative study of the characteristics of French fries produced by deep fat frying and air frying. J. Food Sci. 80: E349-358 (2015)

Tyagi VK, Vasishtha AK. Changes in the characteristics and composition of oils during deep fat frying. J. Am. Oil Chem. Soc. 73: 499-506 (1996)

Waghmare A, Patil S, LeBlanc J, Sonawane S. Comparative assessment of algal oil with other vegetable oils for deep frying. Algal Res. 31: 99-106 (2018)

Yi B, Kim M, Lee J. Effects of emulsifier charges on the oxidative stability in oil-in-water emulsions under riboflavin photosensitization. Food Sci. Biotechnol. 25: 1003-1009 (2016)