碩士學位論文

Quality Characteristics of Deep-Fat Fried Carrots Depending on Frying Oil, Temperature, and Time

濟州大學校 大學院

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ABSTRACT

Deep-fat frying is one of the most cooking methods, which is fast and cheap with good taste. In this study, carrot was deep-fat fried with palm oil (PO), sunflower oil (SO) and blended oil of palm and sunflower oil (PSO 2:8 or 4:6) at different temperature and time and the quality of the deep-fat fried carrots was determined by measuring, moisture content, fat content, color, conjugated diene (CDA) content, *p*-anisidine value, hydroperoxide and fatty acid composition. Among all treatments, the carrot fried at 180°C for 2.5 min in PSO (4:6) contained the lowest moisture content while its fat content was the highest (42.82%). The CDA content of the carrot deep-fat fried with SO was higher than those fried with PO. The tendency of *p*-anisidine value was similarly to the results of CDA content. For fatty acid composition, palmitic acid (C16:0), stearic acid (C18:0), oleic acid (C18:1), and linoleic acid (C18:2) were major fatty acids in all deep-fat fried carrots. The use of blending oil with palm oil and sunflower oil (PSO) was a better choice for deep-fat frying carrots than the use of PO only at the aspects of the unsaturated to saturated fatty acids ratio. These results indicate that the quality of deep-fat fried carrot was not only dependent on the frying oil type but also time and temperature.

Quality Characteristics of Deep-Fat Fried Carrots Depending on Frying Oil, Temperature, and Time

1. 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°C and 190°C, which occurs many components formed during deep-fat frying (Cheo & Min). Consequently, the deep-fat fried products tend to have an attractive golden color and texture (Rahimi et. al, 2017) along with the typical flavor, color, taste, and a crispy surface (Bou et. al, 2012). These deep-fat fried food products have been extensively consumed worldwide (Al-Khusaibi et. al, 2012).

The high temperature for 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 a large number of new compounds (Aniolowska and Kita, 2016). Unfortunately, the use of frying oil for a long time produces off-flavor compounds, which change the stability, color, and nutritional quality of deep-fat fried foods (Choe & Min et. al, 2007). Initially, primary oxidation of free fatty acids, conjugated diene or conjugated triene, and hydroperoxides are produced and alcohol, aldehydes, ketones, and cyclic compounds are produced as secondary products (Kowalski, 1989). These products can worsen the sensory, functional, and nutritional quality of oils and fried products (Waghmare et. al, 2018). Lipid oxidation is very important to determine the oil quality and the shelf life of deep-fat fried foods (Choe & Min, 2007) because it leads to the formation of undesirable compounds on the final product (Nor et. al, 2008). In addition, frying process can make high amounts of oil absorbed in fried product. For example, the fat contents of potato chips, corn chips, and fried noodle usually contain 33, 30, and 14% of fat, respectively (Choe & Min, 2007). In addition to the oil absorption of deep-fat fried product, the fatty acid composition of frying oil can be considered as health issue, especially the proportion of unsaturated and saturated fatty acids (Al-Khusaibi et. al, 2012). Therefore, the selection of frying oil is very important when used for deep-fat frying process (Matthaus, 2007).

Palm oil is extracted from the ripened mesocarp of the palm fruits (Mbo et. al, 2015). This oil is easily available and provides a pleasant odor during deep-fat frying (Matthus, 2007) so that widely used in food industry. This oil is also characterized by higher smoke point and stronger resistance to oxidation than commercial vegetable oils (Marco et. al, 2007). As well, palm oil is high productivity, low price, high oxidation stability, and good plasticity at room temperature. Lastly, palm oil contains about 1% of minor components such as tocopherols, carotenoids, and sterols etc. (Leonardis & Macciola, 2012). Palm oil has a distinct fatty acid and triacylglycerol profile which makes it suitable for many foods and it is the only vegetable oil with almost equal composition ratio of saturated and unsaturated fatty acids (Mbo et. al, 2015). 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, the high content of saturated fatty acids is known to be unhealthful from a nutritional point of view because saturated fatty acids are critical for blood cholesterol leading to cardiovascular diseases. In other hand, vegetable oils like sunflower oil, soybean oil, and canola oil are more beneficial than palm oil because they contain high content of unsaturated fatty acids and low amounts of saturated fatty acids (Matthaus, 2007).

In the frying industry, the change to vegetable oil has been a trend to improve the functional properties and nutritional quality of fried products (Mbo et. al, 2015). But the drawback of a high content of unsaturated fatty acids has disadvantage to low oxidative stability during frying (Ai-Khusaibi et al., 2012). Blending two or more oils is another option to make new specific frying oil (Mbo et. al, 2015). The Farhoosh et. al, (2009) study showed total polar compounds content and p-anisidine value of blending oil with canola oil and palm olein were lower than canola oil blended with other oils (Farhoosh et. al, 2009). In this study, carrots were deep-fat fried with blending oil of palm oil and sunflower oil at different frying temperature and time and the quality characteristics of deep-fat fried carrots were investigated.

2. Materials and Methods

2.1. 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).

2.2. 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, sunflower oil, and blending oil with palm oil and sunflower oil at the ratio of 2:8 and 4:6 (PSO 0:10, PSO 10:0, PSO 2:8, PSO 4:6) were used as frying oil. 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. The oil in deep-fat fried carrots were extracted with Soxhlet apparatus following of AOAC methods 981.05 for lipid oxidation analysis.

2.3. Moisture and fat contents

Moisture and fat contents of deep-fat fried carrots were determined according to AOAC methods 981.05.

2.4. Color analysis

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

2.5. Fatty acids analysis

Fatty acids were derivatized to fatty acid methyl esters (FAME) using /MeOH (14% boron trifluoride) according to AOCS methods 981.05. The FAME was analyzed by gas chromatography (GC-17A, Shimadzu, Kyoto, Japan) with a SP-2560 column (100 mm 0.25 mm, 0.20 mm 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. 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 FAME standards (Sigma-Aldrich).

2.6. CDA value

Conjugated dienoic acids (CDA) which were primary oxidation products were measured by AOCS Official method Ti 1a-64. The extracted oil (0.1 g) from deep-fat fried carrots were mixed with isooctane (25 mL) in measuring flasks 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.

$$\text{Conjugated dienoic acid (\%)} = \frac{0.84 \times A_{233}}{bc - K_0} \times 100$$

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}

2.7. Analysis of lipid hydroperoxide

Lipid hydroperoxides were quantified by method (Yi et. al, 2016). 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 for 1 min three times, they were centrifuged at 2000 x 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 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-spectrometer (Mecasys). The concentration of lipid hydroperoxides was calculated by a standardcurve of cumene hydroperoxide.

2.7. *p*-Anisidine value

The *p*-anisidine value was determined by AOCS Official method Cd 18-90. The extracted oil (0.5 g) from deep-fat fried carrots were mixed isooctane (25 mL) in measuring flasks. The absorbance at 350 nm was measured by UV/VIS spectrophotometer (Mecasys). The oil solution (5 mL) was mixed with 0.25% p-anisidine (1 mL) solution and incubated at room temperature for 10 min. The absorbance at 350 nm was measured and the p-anisidine values were calculated as following equation.

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

A_s: Absorbance of the oil solution after reaction with the p-anisidine regent

A_b: Absorbance of the oil solution alone

W: Mass of the sample (g)

2.7. 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 $p<0.05$

3. Results and Discussion

3.1. Moisture and fat contents

The effect of frying oil, temperature, and time on the moisture and fat contents of deep-fat fried carrots is shown in Table 1 and 2. The moisture contents of deep-fat fried carrots decreased after frying while the fat contents increased. These values 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%. When carrots were deep-fat fried at 180°C and 190°C, the moisture contents were significantly decreased with increased 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 min and 30 min were 35.8 and 6.9%, respectively (Shyu et al., 2005). When the frying temperature increased from 180 to 190°C for 2 min, the moisture contents of deep-fat fried carrots decreased. For example, when deep-fat fried carrots for 2 min with PSO 10:0 at 180°C and 190°C, the fat contents were 22.12% and 3.18% respectively. Comparing by frying oil, the moisture content of deep-fat fried carrots with the sunflower oil (PSO 0:10) was the highest. Frying at the same time and temperature, the moisture content of fried carrots with sunflower oil and palm oil was 17.21% and 8.42%, respectively. When deep-fat fried with sunflower oil (PSO 0:10) 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 palm oil, respectively. Therefore, the moisture content in deep-fat fried carrots was depended on frying time, temperature, and oil type.

Fat contents of deep-fat fried carrots were significantly increased with increasing frying time (p<0.05, Table 1 and 2). The fat contents of deep-fat fried carrots at 180°C in PSO 4:6 for 2.5 min was the highest (42.82%) and PSO 0:10 (sunflower oil only) for 1 min was the lowest (19.86%). When carrots were deep-fat fried at

180°C to 190°C, the fat contents were significantly increased (p<0.05). The fat contents in deep-fat fried carrots increased when moisture contents decreased. Similar results were observed in the study of Kita et. al (2007). They reported that the oil contents of vacuum fried potato chips increased as frying time increased from 25 to 500 sec at 118°C, 132°C, and 144°C (Garayo & Moreira, 2002). When frying temperature increased to 118 °C, the oil contents increased (Garayo & Moreira, 2002). Kita et al. (2007) also reported 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 oil absorption which directly impacts on the crispiness of fried products. The high temperature in frying oil leads to fast development of hard surface which is consequently favorable for fried products (Garayo & Moreira, 2002).

3.2. Color

Table 1 and 2 shows 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). When carrots of deep-fat fried at 180°C for 1 min and 2.5 min with all types of frying oil, the L* values ranged from 47 to 48 and 37 to 45, respectively. Similar results were reported that the L* values of the vacuum-fried carrots at 100°C for 5 min 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 increasing frying time. The loss of lightness might be caused by low moisture content in fried carrots (Shyu et. al, 2005). Also, when carrots were fried for 2 min, the L* values of deep-fat fried carrots at 190°C were lower than those at 180°C. The study of Salehi (2018) indicated that as frying time increased, the L* values of deep-fat fried carrots at 190°C decreased more rapidly than at 170°C. When frying temperature increased from 130 to 190°C for 3 min with sunflower oil, the L* values of carrots decreased from 55.74 to 49.21, respectively. The study of Lee et al. (2002) indicated that the L*, a*, and b* values of deep-fat fried potato strips were decreased as deep-fat fried temperature increased. When potato strips were deep-fat fried at 150°C, 170°C, and 190°C, color values were decreased after 5 min. When carrots were deep-fat fried for 2.5 min at 180°C, the L* values of carrots with sunflower oil were higher than other frying oils. The a* and b* values also showed similar results to L* values. These reduction is possibly related to the carotenoid contents which are unstable at high temperature of fyring (Shyu et al., 2005). In summary, the color values of deep-fat fried carrots were depended time and oil type and frying temperature.

Table 1. Moisture and fat contents and color of deep-fat fried carrots frying with palm oil, sunflower oil, and blended oil at 180°C for 1, 1.5, 2, 2.5 min

Frying oil ratio (P:S)	Time (min)	Moisture (%)	Fat(%)	Color		
				L*	a*	b*
Raw	-	94.12 ± 0.30^{a}	-	47.54 ± 1.19^{abc}	25.72 ± 2.29^{cd}	33.71 ± 1.85^{abc}
0:10	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}	$35.66.\pm1.63^{ab}$
	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}
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}	$32.30.\pm1.27^{abc}$
	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}
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}
10:0	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 and fat contents and color of deep-fat fried carrots frying with palm oil, sunflower oil, and blended oil at 190°C for 0.5, 1, 1.5, 2 min

Frying oil ratio (P:S)	Time (min)	Moisture (%)	Fat(%)	Color		
				L*	a*	b*
Raw	-	94.12±0.30^{a}	-	47.54±1.19^{bcd}	25.72±2.29^{ab}	33.71±1.85^{abc}
0:10	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}
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}
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}
10:0	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.

3.3. Fatty acids composition

Fatty acid composition of deep-fat fried carrots at 180°C and 190°C were shown in Table 3 and 4. Palmitic acid (C16:0), stearic acid (C18:0), oleic acid (C18:1), and linoleic acid (C18:2) were major fatty acids in deep-fat fried carrots. When comparing the results by frying time and temperature, the fatty acids were not significantly different (p<0.05). The study of Shyu et al. (2005) indicated that linoleic acid and linolenic acid for all oils were significant decreased during vacuum frying for 8 to 48 h. After deep-fat fried with blending oil (sunflower oil and palm oil) and palm oil for 240 min at 180°C, the content of palmitic acid was increased and linolenic acid was decreased (Marco et al., 2007). Similar results were observed in the study of Tyagi and Vasishtha (1996). When potato chips fried at 180°C for 70 h with soybean oil, the loss of unsaturated fatty acids was 38.8%. Also, when potatoes were deep-fat fried for 70 h with soybean oil at 180 and 190°C, the loss of unsaturated fatty acids at 190°C (43.6%) was higher than 180°C (38.8%). In this study, the composition of fatty acids were not changed during frying time because the frying time was only up to 2.5 min. When compared to frying oil, the fatty acids composition was not significantly different (p<0.05). The saturated fatty acids of deep-fat fried carrots by palm oil (PSO 10:0) was the highest (49%) and those by sunflower oil (PSO 0:10) was the lowest. Blending with sunflower oil made the increase of unsaturated fatty acids. Palm oil contained 45% of unsaturated fatty acids and blnded oil with sunflower oil, PSO 2:8 and PSO 4:6 contained about 70% and 80% unsaturated fatty acids, respectively. Thus, the blending oil of PSO 2:8 and PSO 4:6 were better than palm oil itself from a nutritional point of view because the high content of saturated fatty acids is known to cause blood cholesterol and cardiovascular diseases (Matthaus, 2007).

Table 3. Fatty acids composition of deep-fat fried carrots at 180°C for 1, 1.5, 2, and 2.5 min

Ratio (P:S)	Time (min)	Fatty acid					
		16:0	18:0	18:1	18:2	Saturated	Unsaturated
0:10	1	6.56±0.03^{f}	3.23±0.02^{d}	29.11±0.15^{e}	56.35±0.78^{ab}	9.79±0.05^{f}	85.46±0.92^{ab}
	1.5	6.53±0.12^{f}	3.26±0.05^{d}	29.27±0.15^{e}	56.77±0.45^{a}	9.79±0.15^{f}	86.04±0.60^{a}
	2	6.52±0.03^{f}	3.27±0.04^{d}	28.92±0.25^{e}	55.7b±0.55^{b}	9.79±0.03^{f}	84.70±0.71^{b}
	2.5	6.55±0.05^{f}	3.29±0.04^{d}	29.12±0.34^{e}	56.09b±0.77^{ab}	9.84±0.05^{f}	85.21±1.06^{ab}
2:8	1	13.30±0.11^{e}	3.90±0.09^{bc}	31.15±0.48^{d}	47.25±0.85^{d}	17.19±0.15^{e}	78.38±1.33^{d}
	1.5	13.38±0.09^{e}	3.78±0.21^{bc}	31.93±0.04^{c}	48.33±0.56^{c}	17.17±0.27^{e}	80.26±0.56^{c}
	2	14.07±0.22^{d}	3.78±0.07^{c}	31.78±0.12^{c}	47.30±0.08^{d}	17.85±0.20^{d}	79.08±0.13^{d}
	2.5	13.82±0.25^{d}	3.76±0.06^{c}	30.99±0.11^{d}	48.45±0.64^{c}	17.58±0.29^{de}	79.44±0.55^{cd}
4:6	1	20.94±0.24^{c}	3.93±0.05^{bc}	32.79±0.73^{b}	38.59±0.42^{e}	24.88±0.25^{c}	71.38±0.66^{e}
	1.5	21.07±0.08^{c}	3.82±0.04^{bc}	32.73±0.59^{b}	37.66±0.40^{f}	24.89±0.11^{c}	70.40±0.58^{e}
	2	21.24±0.04^{c}	3.82±0.05^{bc}	32.55±0.35^{bc}	38.52±0.44^{ef}	25.06±0.06^{c}	71.07±0.74^{e}
	2.5	21.18±0.16^{c}	3.99±0.32^{b}	32.79±0.28^{b}	38.28±0.15^{ef}	25.17±0.43^{c}	71.06±0.21^{e}
10:0	1	45.46±0.33^{a}	4.54±0.11^{a}	36.44±0.32^{a}	8.89±0.20^{g}	50.00±0.41^{a}	45.33±0.37^{f}
	1.5	45.19±0.41^{ab}	4.49±0.07^{a}	36.53±0.05^{a}	8.35±0.14^{g}	49.69±0.46^{ab}	44.87±0.16^{f}
	2	45.30±0.46^{a}	4.57±0.05^{a}	36.56±0.38^{a}	8.63±0.36^{g}	49.87±0.45^{ab}	45.19±0.43^{f}
	2.5	44.91±0.17^{b}	4.50±0.03^{a}	36.51±0.33^{a}	8.41±0.20^{g}	49.41±0.17^{b}	44.92±0.53^{f}

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 4. Fatty acids composition of deep-fat fried carrots at 190°C for 0.5, 1, 1.5, and 2 min

Ratio (P:S)	Time (min)	Fatty acid					
		16:0	18:0	18:1	18:2	Saturated	Unsaturated
0:10	0.5	6.54±0.03[d]	3.19±0.02[d]	29.01±0.09[f]	56.30±b0.49[a]	9.73±0.02[d]	85.31±0.57[a]
	1	6.51±0.04[d]	3.21±0.03[d]	28.97±0.07[f]	56.20±0.52[a]	9.72±0.06[d]	85.17±0.53[a]
	1.5	6.51±0.09[d]	3.22±0.05[d]	29.00±0.03[f]	56.76±0.77[a]	9.73±0.13[d]	85.76±0.80[a]
	2	6.45±0.05[d]	3.21±0.01[d]	29.05±0.02[f]	56.73±0.50[a]	9.66±0.05[d]	85.78±0.50[a]
2:8	0.5	14.04±0.18[c]	3.85±0.07[b]	30.94±0.29[de]	48.14±0.17[b]	17.89±0.25[c]	79.08±0.12[bc]
	1	14.04±0.27[c]	3.76±0.05[bc]	31.69±0.27[c]	47.74±0.32[b]	17.80±0.21[c]	79.43±0.40[b]
	1.5	14.05±0.22[c]	3.74±0.04[bc]	30.38±0.22[e]	47.81±0.53[b]	17.80±0.24[c]	78.19±0.72[c]
	2	13.88±0.29[c]	3.75±0.09[bc]	31.56±0.29[cd]	47.95±0.14[b]	17.63±0.33[c]	79.51±0.42[b]
4:6	0.5	20.86±0.24[b]	3.82±0.10[b]	32.81±0.33[b]	38.79±0.64[cd]	24.67±0.24[b]	71.59±0.96[d]
	1	20.81±0.49[b]	3.83±0.03[b]	33.05±0.85[b]	38.17±0.19[d]	24.63±0.47[b]	71.22±0.96[d]
	1.5	21.01±0.21[b]	3.65±0.14[c]	32.42±0.62[b]	38.77±0.58[cd]	24.66±0.34[b]	71.19±1.08[d]
	2	20.63±0.50[b]	3.78±0.09[b]	32.48±0.91[b]	39.00±0.39[c]	24.41±0.45[b]	71.48±1.18[d]
10:0	0.5	45.12±0.14[a]	4.51±0.02[a]	36.49±0.35[a]	8.50±0.35[e]	49.63±0.13[a]	44.99±0.48[e]
	1	45.32±0.38[a]	4.53±0.06[a]	36.75±0.04[a]	8.37±0.02[e]	49.85±0.44[a]	45.12±0.04[e]
	1.5	45.19±0.26[a]	4.56±0.06[a]	36.85±0.24[a]	8.37±0.26[e]	49.74±0.31[a]	45.21±0.28[e]
	2	45.48±0.21[a]	4.57±0.06[a]	36.57±0.11[a]	8.48±0.41[e]	50.05±0.17[a]	45.04±0.32[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.

3.4. CDA value

Conjugated diene is produced owing to the oxidation of polyunsaturated fatty acids (Kim et al., 2013). The conjugated dienoic acids (CDA) values of the extracted oil from deep-fat fried carrots at different frying oil, temperature, and time are shown in Fig 1. The initial CDA values of PSO 0:10 to 10:0 before frying were 0.10, 0.08, 0.09, and 0.09%, respectively. After deep-fat frying, the CDA values were increased. The CDA value of deep-fat fried carrots with palm oil (PSO 0:10) at 180°C for 1.5 min was the lowest, about 0.12% and the value of deep-fat fried carrots by sunflower oil (PSO 0:10) for 2.5 min was the highest (0.46%). In the study of Chung et. al (2004), the CDA contents of fried dough that had been heated long period tended to be high (Lee et. al, 2002). The reason for this is higher stability of the conjugated diene than a nonconjugated system during oxidation or frying processing (Chung et. al, 2004). The CDA values with blending oil of soybean oil and palm olein at a ratio 6:4 at 180°C for 170 h were less than 0.2% to 0.74%, respectively (Song et al., 2017). On the contrary, the CDA values were not affected by frying temperature at 180 and 190°C. As the ratio of sunflower oil increased, the CDA value increased. For example, when deep-fat fried carrots with sunflower oil (PSO 0:10) at 180°C for 2 min and palm oil (PSO 10:0), the CDA values were significantly increased (0.53% and 0.24%, respectively). Also the CDA values of blending oil of PSO 2:8 and PSO 4:6 were lower than that of sunflower oil (PSO 0:10). Because the sunflower oil (PSO 0:10) contained high amounts of unsaturated fatty acids, the CDA could be easily formed by lipid oxidation. Soybean oil had higher CDA value than lard because of high concentration of polyunsaturated fatty acids (Kim et al., 2013). Abdulkarim et al. (2007) indicated that the low CDA value in *moringa oleifera* seed oil was indication of great oxidative stability of the oil with the high percentage of monounsaturated fatty acids and oleic acids. Sunflower oil (PSO 0:10) has low content of monounsaturated fatty acids and high content of polyunsaturated fatty acids compared to other edible oils so high in the CDA values.

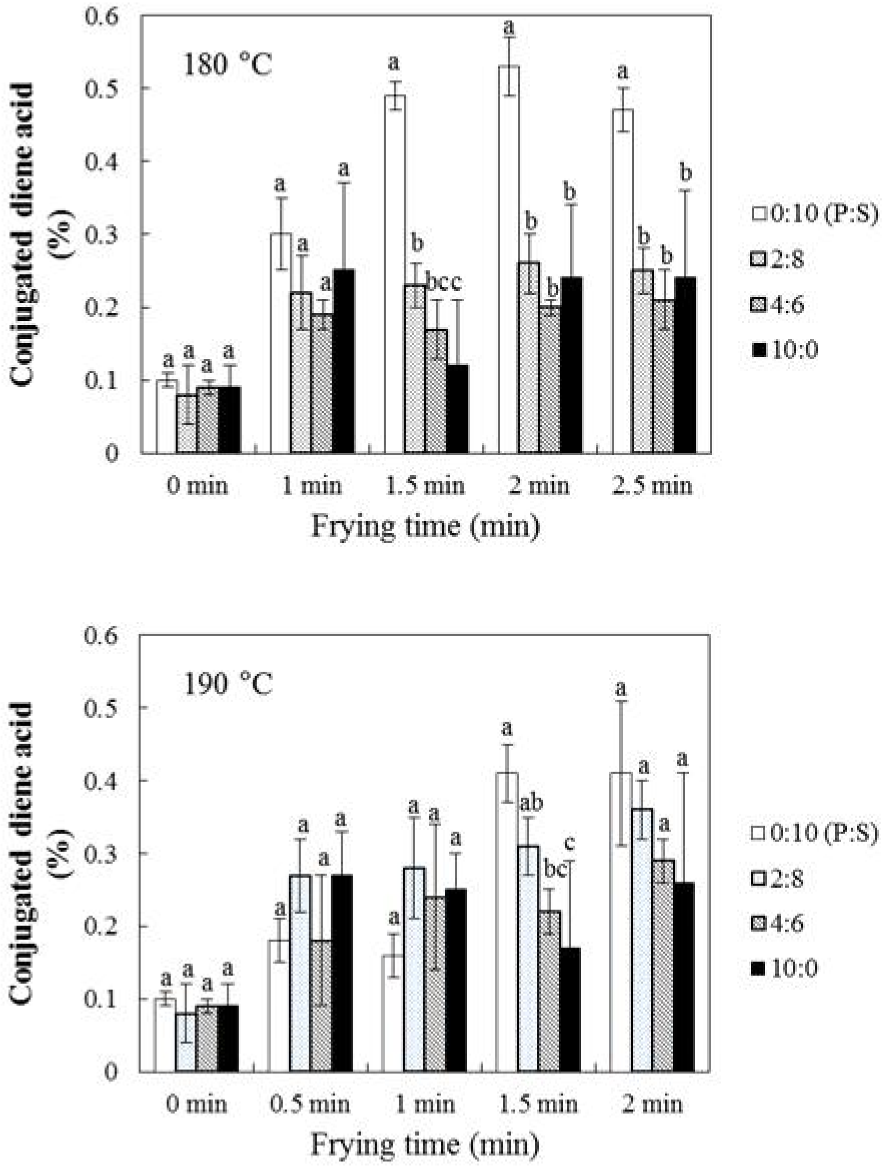

Fig. 1. Conjugated dienoic acid (CDA) contents of deep-fat fried carrots with different frying oils, temperature, and time. Dissimilar small alphabets on a line are significantly different within frying time at p<0.05.

3.5. Lipid hydroperoxide contents

Hydroperoxides are the primary products formed during oxidation, but they are highly unstable and rapidly decomposed to secondary oxidation products. These secondary oxidation products include aldehydes, alcohols, and ketones (Choe & Min, 2006). Thus, though hydroperoxide is a common indicator of lipid oxidation, its use is limited to the earlier stages of oxidation (Guillermo, 1999). Fig. 2 shows lipid hydroperoxide of deep-fat fried carrots by frying oil, temperature, and time. The hydroperoxide content with palm oil (PSO 0:10) at 180°C for 1.5 min was the lowest about 1.5 mmol CuOOH/kg. When carrots were vacuum fried, the hydroperoxide increased as frying time increased (Shyu et. al, 2005). But in this study, hydroperoxide contents were not significantly different with frying time and temperature, because first the frying time was short to form hydroperoxides or hydroperoxide was not stable during frying at high temperature and decomposed to hydropxyl radicals and alkoxyl radicals by hemolysis of the peroxide bond (Choe & Min, 2007). The hydroperoxide formation was depending on frying oil type. For example, hydroperoxide of deep-fat fried carrots with sunflower oil (PSO 0:10) and palm oil (PSO 10:0) at 180°C for 1.5 min were about 9 mmol CuOOH/kg and 1.5 mmol CuOOH/kg respectively. When carrots were deep-fat fried with sunflower oil with high composition of unsaturated fatty acids, the hydroperoxides were formed easily compared to palm oil with low in unsaturated fatty acids. Choe and Min (Choe & Min, 2007) reported that the oil containing high amount of unsaturated fatty acids is more quickly oxidized than less unsaturated oil. Therefore, the sunflower oil (PSO 0:10) produced more hydroperoxide than other oils.

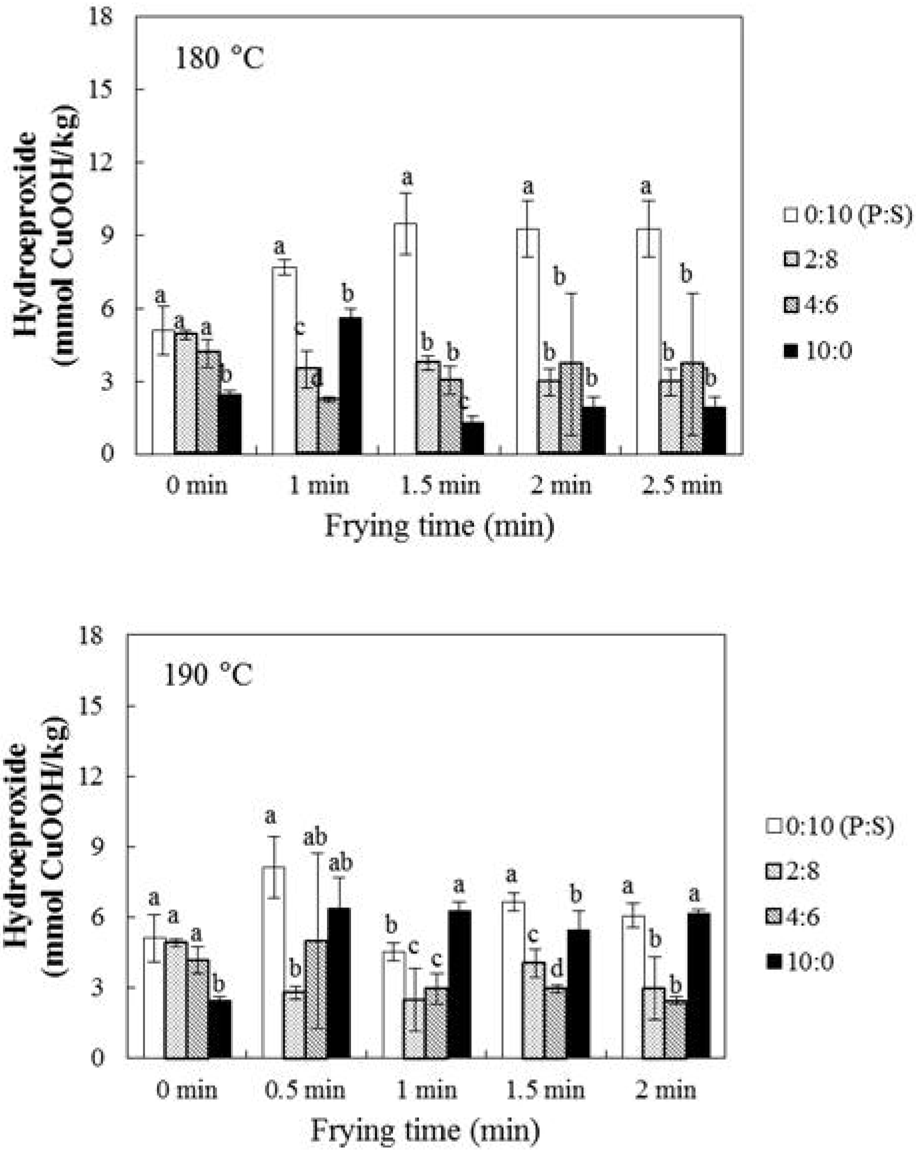

Fig. 2. Lipid hydroperoxide contents of deep-fat fried carrots with different frying oils, temperature, and time. Dissimilar small alphabets on a line are significantly different within frying time at $p<0.05$.

3.6. *p*-Anisidine value

One of the most analytical methods for measurement of lipid oxidation is the p-anisidine value (Aniolowska & Kita, 2016). Aldehydes formed during lipid oxidation are secondary oxidative products and the non-volatile portion of carbonyls remains in the frying oil (Felix & Roman, 2009). Anisidine value has been rated as the most reliable for determining fat and oil oxidation as it measures the accumulation of secondary oxidation compounds that are more stable than hydroperoxides (Flores et. al, 2018). The *p*-anisidine values of the deep-fat fried carrots by frying oil, temperature and time are shown in Fig. 3. The initial *p*-anisidine values of PSO 0:10, 2:8, 4:6, and 10:0 before frying were 4.33, 6.05, 4.92, and 8.68, respectively. The value of deep-fat fried carrot with palm oil (PSO 0:10) at 180°C was the lowest. When carrots were deep-fat fried, the p-anisidine value with PSO 0:10 at 190°C for 2 min was the highest (43.52). The *p*-anisidine values were significantly increased with increased frying time ($p<0.05$). The study (Lee et al., 2002) reported that the *p*-anisidine value of flour dough with soybean oil for 20 h has increased by about 50%. The study of Yu et al. (2018) indicated similar result. When potato chips at 180°C for 4 min with soybean oil were deep-fat fried repeatedly 80 times, the value was increased from 3 to 47. Along with CDA value, the *p*-anisidine value was not affected by frying temperature of 180 and 190°C while these values significantly affected by frying oil type. The initial *p*-anisidine value of sunflower oil (PSO 0:10) was lower than other frying oils but after deep-fat frying it was increased dramatically than other oils. On the other hand, the initial value of palm oil had highest (8.68) but as frying time increased, it was the less increased. Also the values of deep-fat fried carrots with blending oil were higher than palm oil but lower than sunflower oil. Similar results were reported in the study of Matthäus (2006). They reported that when deep-fat fried at 175°C for more than 6 hours, *p*-anisidine value of vegetable oils with highest amount of polyunsaturated fatty acids were higher than those of palm olein oil. Therefore, the *p*-anisidine value of sunflower oil (PSO 0:10) was highest among frying oils because it contained the amount of polyunsaturated fatty acids. Therefore, it seems that blending oil had greater oxidative stability than sunflower oil (PSO 0:10) only used for frying.

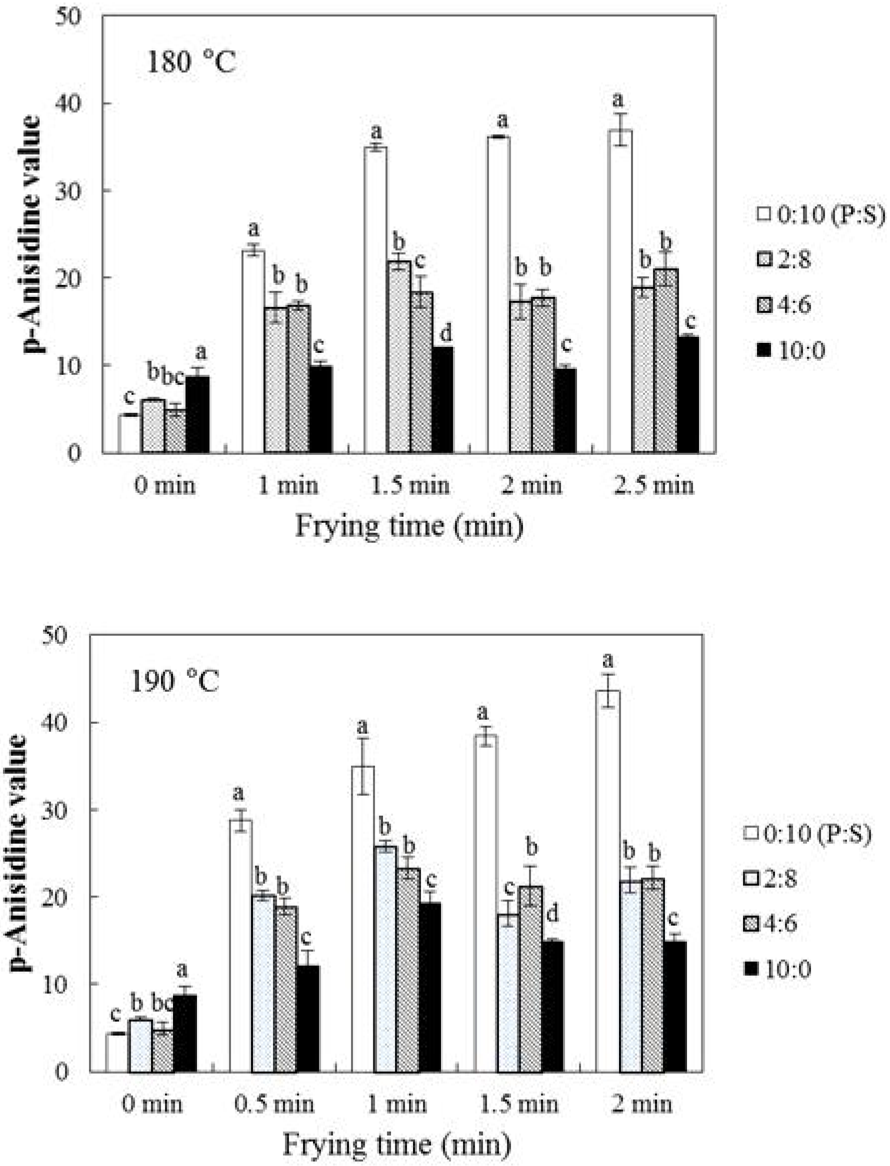

Fig. 3. p-Anisidine value of deep-fat fried carrots with different frying oils, temperature, and time. Dissimilar small alphabets on a line are significantly different within frying time at $p<0.05$.

4. Conclusions

In this study, carrots were deep-fat fried at different frying temperature, time, and oil type. Moisture contents and color values of deep-fat fried carrots were decreased as frying time, temperature, and sunflower oil (PSO 0:10) ratio increased. On the contrary, when frying time and palm oil (PSO 10:0) ratio were increased, the fat contents were decreased. Fatty acids composition was not affected by frying time and temperature. Unsaturated fatty acids contents of the deep-fat fried carrots with sunflower oil was higher than those of other frying oils (86%). When deep-fat fried with blending oil, a higher unsaturated fatty acids contents were than palm oil (79%). Oxidative stability of deep-fat fried carrots depended on frying time and oil type. The CDA value, hydroperoxide, and p-anisidine value were low when fried with palm oil (PSO 0:10) at 180℃ for 1.5 min. Palm oil was the best oil for the prevention of oxidation during frying of carrots; however, for nutritional aspect, palm oil was not a great choice with low composition of unsaturated fatty acids. Therefore, blended oils (PSO 2:8 and 4:6) were the good for frying carrots with better oxidative stability than sunflower oil and higher unsaturated fatty acids than palm oil only.

국문요약

본 연구에서는 팜유, 해바라기유, 혼합유에 제주산 당근을 유탕처리한 스낵의 일반성분과 산화안정성을 살펴보았다. 유탕 시간과 온도 및 식용유지를 달리 처리 한 당근 스낵들의 수분함량, 지방함량, 색도 및 지방산을 분석하였고, 산화안정성은 CDA value, Lipid hydroperoxide, p-Anisidine value 방법으로 분석하였다. 일반성분의 경우 유탕 시간이 증가함에 따라 수분과 색도의 값이 낮아지는 경향을 보였고, 지방함량의 경우 일부 조건에서 증가하는 경향을 보였다. 또한 온도가 증가함에 따라 일부 조건에서 수분과 색도가 감소하였고, 지방함량은 증가하였다. 해바라기유로 처리한 당근 스낵의 경우 1분간 유탕처리를 하였을 때 다른 식용유지에 비해 31.96%의 높은 수분함량과 19.86%의 낮은 지방함량을 보였다. 지방산조성의 경우 유탕시간이 짧아 유탕시간이나 온도에 따른 차이가 나타내지 않았으며, 해바라기유로 처리한 당근 스낵에서 약 86%의 가장 높은 불포화지방함량, 팜유처리한 경우 약 50%의 가장 높은 포화지방산 함량을 나타냈다. 또한 혼합유로 처리한 당근 스낵의 불포화지방산의 경우 해바라기유 보다는 낮지만 팜유에 비해 월등히 높은 함량을 보였다. 산화안정성의 경우 CDA value와 p-Anisidine value의 경우 대체로 식용유지에 영향을 받는 경향을 보였고, Lipid hydroperoxide의 경우 영향을 받지 않는 것으로 나타났다. 또한 모든 실험의 값을 종합했을 때, 180℃, 1.5 분 팜유로 처리한 당근 스낵에서 가장 높은 산화안정성을 보였다. 또한 혼합유로 처리한 당근 스낵의 경우 팜유보다는 낮은 산화안정성을 보였지만, 해바라기유 처리 스낵에 비해 높은 산화안정성을 보였다. 따라서 산화안정성의 경우 높은 포화지방산함량을 나타내는 팜유로 처리한 스낵이 가장 높았지만, 영양적 측면까지 고려했을 때 팜유보다는 낮지만, 해바라기유보다는 높은 혼합유를 사용하여 유탕처리 하는 것이 바람직 할 것으로 생각된다.

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