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Chemical Characteristics of Potato Chips Fried in Repeatedly Used Oils

반복 사용한 기름에 튀긴 감자칩의 화학적 특성

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ABSTRACT

Chemical Characteristics of Potato Chips Fried in Repeatedly Used Oils

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The objective of the study was to evaluate chemical properties of potato chips fried in repeatedly used oils. Potato chips were deep-fat fried in refined coconut oil (PRCO: potato chips), refined soybean oil (PRSO), pure olive oil (PPOO), and vegetable shortening (PVST). The potato chips were fried in 1, 20, 40, 60, and 80 times repeatedly used oils. Oils were extracted from PRCO (RCO: extracted oil), PRSO (RSO), PPOO (POO), and PVST (VST) and analyzed for oxidative stability. The PVST was higher in hexanal than the PRSO and PPOO ($p<0.05$). Nonanal and 2-decenal were most detected in the PPOO ($p<0.05$) and rarely in the PRSO. 2,4-Decadienal was least detected in the PRCO ($p<0.05$). PVST was lower in acrylamides than the other fried potato chips (p<0.05). Total polar compounds (TPC) in the RCO was lower than in the other extracted oils at the 80th repetition (p<0.05). Conjugated dienes (CD) were the highest in the RSO and the lowest in the RCO (p<0.05). Peroxide value (PV) of the RCO continuously increased during the repeated frying (p<0.05), while those of the POO and VST little changed. *p*-Anisidine value (*p*-AV) of the RCO was the lowest at all the repetitions (p<0.05), while those of the VST were the highest at the 1st, 20th, 40th, and 60th repetitions (p<0.05). Total oxidation (Totox) value of the RCO was the lowest at all the repetitions (p<0.05). In this study, PRCO might have less oxidative products considering aldehydes, CD, TPC, *p*-AV, and Totox value.

Keywords: repeated deep-fat frying, frying oil, potato chips, aldehydes, oxidative stability

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INTRODUCTION

Deep-fat frying of foods is a commonly used cooking method using oil as a heating medium, providing positive sensory characteristics on foods such as crispy texture, juicy flavor, and brownish color (Kim and others 2010). Various fried foods such as chicken nuggets, potato chips, and shrimp fritters are produced using deep-fat frying process. Among these fried foods, potato chips are the most popular. Since the fat content of potatoes is about 0.1%, oil in potato chips mainly comes from frying oil (USDA 2016).

Although deep-fat frying provides good sensory properties to fried foods, negative effects on the foods have been also reported. Repeated use of frying oil accelerates the deterioration of oil, which can directly affect the quality of the fried foods, producing organoleptically undesirable and somewhat harmful substances (Choe and Min 2007). Components such as acrylamides and aldehydes may be produced by degradation of frying oils and transferred into food matrix (Kim and others 2010). It was reported that oils with less unsaturated fatty acids showed slower oxidation rate (Choe and Min 2007). Repeated use and type of oil used in a deep-fat frying can be major determinants of the quality of fried foods (Mellema 2003).

Volatile compounds such as aldehydes, alcohols, and hydrocarbons are also produced during deep-fat frying. Among them, aldehydes are known to be harmful to human (Katragadda and others 2010). They act as not only flavor compounds but also toxic substances to human health (Cho and others 2014). Aldehydes such as alkanals, 2-alkenals, and 2,4-alkadienals are produced during deep-fat frying, and quantification of these aldehydes can provide the information to evaluate the quality of fried foods (Dobarganes and others 2000).

Physicochemical properties of frying oils and potato chips after deep-fat frying have been reported (Karakaya and Şimşek 2011; Granda and others 2004; Mellema 2003). Previous studies concerning the effect of repeatedly used frying oils on potato chips have usually focused on oil contents and physicochemical characteristics of the chips (Ufheil 1996; Warner 1994). However, aldehydes in potato chips and chemical properties of the oils in potato chips were little studied.

The objective of this study was to evaluate chemical characteristics of potato chips fried in repeatedly used oils and oils extracted from the fried potato chips. Refined coconut oil, refined soybean oil, pure olive oil, and vegetable shortening, which have been generally used as frying oils, were used for the test.

MATERIALS AND METHODS

1. Materials

Refined coconut oil, refined soybean oil, pure olive oil (a mixture of refined and virgin olive oil), vegetable shortening (a mixture of palm oil and palm stearin), and fresh potatoes were purchased from local markets in Seoul, Korea. Hexanal, nonanal, 2-decenal, 2,4-decadienal, *p*-anisidine, acrylamide, acrylamide-d_3, boron trifluoride (BF_3)-methanol solution, and standard mixture of 37 fatty acids methyl esters (FAME) were purchased from Sigma-Aldrich (St. Louis, MO, USA). QuEChERS (quick, easy, cheap, effective, rugged, and safe) extract tubes for acrylamides and dispersive SPE (solid phase extraction) were purchased from Agilent Technologies (Palo Alto, CA, USA). Acetonitrile, acetic acid, chloroform, ether, hexane, iso-octane, potassium iodide, starch, sodium chloride, sodium hydroxide, and sodium thiosulfate were purchased from Samchun Chemical (Seoul, Korea). All chemicals were of analytical reagent grade.

2. Sample preparation

To prepare potato chips, fresh potatoes were washed, peeled, and cut into slices of 4 mm thickness using a potato slicer. They were immersed in cold water for 12 h and then pat dried with paper towels. Each oil (4 L) was placed in an electric fryer with 6 L capacity (Delki, Goyang, Korea) and heated to 180±5°C. The potato chips (200 g) were fried for 4 min. After the chips were taken out, the oil was heated again for 2 min before the next frying. This process was repeated 80 times. Potato chips fried in 1, 20, 40, 60, and 80 times repeatedly used oils were packaged in polyethylene pouches (Rollpack, Pyeongtaek, Korea) using a vacuum packaging machine (M-6TM, Leepack Co., Incheon, Korea) and stored at -20°C until analyzed further. Potato chips fried in refined coconut oil, refined soybean oil, pure olive oil, and vegetable shortening were abbreviated as PRCO, PRSO, PPOO, and PVST, respectively.

3. Determination of moisture and crude fat contents in potato chips

Moisture and crude fat contents in the potato chips were measured according to the AOAC Official Method (1995) 950.46 and 960.39, respectively.

4. Determination of volatile aldehydes in potato chips

Volatile aldehydes in the potato chips were determined by a HS-SPME-GC/MS method described by Sanches and others (2005) with a slight modification. Each ground sample (0.1 g) in a headspace glass vial (10 mL, 22.5×46 mm, Supelco, Bellefonte, PA, USA) was heated in a water bath at 70°C for 5 min. For the absorption of volatile aldehydes, fiber coated with divinylbenzene/carboxen/polydimethylsiloxane (50/30 μm film thickness, Supelco) was inserted into the vial, and kept in the water bath at 70°C for 20 min. Aldehydes were desorbed for 3 min by inserting the fiber into injection port (250°C) of gas chromatography (QP2010 Plus, Shimadzu Co., Kyoto, Japan) equipped with a 0.75 mm ID glass injection liner, a capillary column (DB-5, 30 m x 0.25 mm x 0.25 μm, J&W Scientific, Folsom, CA, USA), and a mass selective detector. Pressure of carrier gas, helium, was 70 kPa. Oven temperature was programmed to hold at 40°C for 1 min, to increase at 20°C/min to 120°C held for 8 min, and to increase at 20°C/min to 260°C held for 3 min. The MS detector was operated in full scan mode with an electron energy of 70 eV and a scanning range of m/z 35-300 at 0.45 scan/s. Among detected volatile compounds, hexanal, nonanal, 2-decenal, and 2,4-

decadienal were quantified using external standards.

5. Determination of acrylamides in potato chips

The samples were prepared using QuEChERS extract tubes and dispersive SPE, following a method described by Agilent Technologies (2013) with a slight modification. Each ground sample (2 g) was placed into a 50 mL centrifuge tube. Hexane (8 mL) was added for defatting and vortexed for 1 min. Ten mL of water, 9.9 mL of acetonitrile, and 100 μL of acrylamide-d_3 (100 μg/mL), as an internal standard, were added and vortexed for 1 min. QuEChERS extraction mixture (NaCl 0.5 g + $MgSO_4$ 4.0g) was added and vortexed for 1 min followed by centrifugation at 4,000 rpm for 5 min. Six mL aliquot of acetonitrile layer was transferred to QuEChERS dispersive SPE 15 mL tube, which contained 150 mg Primary Secondary Amine, 150 mg C18EC, and 900 mg $MgSO_4$. The tube was vortexed for 1 min and centrifuged at 4,000 rpm for 5 min. Three mL of the extract was moved into conical tube and evaporated to 0.5 mL using vacuum concentrator (Modulspin 40, Hanil, Gimpo, Korea) and transferred to glass vial (2 mL, Agilent Technologies) for analysis. Acrylamides in the samples were determined using gas chromatography (QP2010 Plus, Shimadzu Co.) equipped with a 0.75 mm ID glass injection liner, a capillary column (DB-23, 30 m x 0.25 mm x 0.25 μm, J&W Scientific), and a mass selective detector. GC/MS operating conditions followed a method described by Matthäus (2004). Oven temperature was programmed to hold at 80°C for 2 min and then increased at 10°C/min to 220°C held for 1 min. An interface temperature and ion source temperature were of 250°C and 200°C, respectively. The MS detector was operated in SIM (selected ion monitoring) mode. Ions with masses (m/z) 74 and 58 were selected for identification of acrylamide-d_3, and 71 and 55 for identification of acrylamide. The quantification was carried out by comparing the intensity of the masses 71 and 74.

6. Oil extraction from fried potato chips

Potato chips were dried in a freeze-dryer (NB-504, Ilshin Co., Dongducheon, Korea). The dried samples were packaged using the vacuum packaging machine and stored at -20°C until used for oil extraction. Dried potato chips were ground for 5 s using a food processor (HMF-347, Hanil Electric Co., Seoul, Korea). n-Hexane was added in the ground potato chips for oil extraction. The ratio of the ground sample and solvent was 1:4 (w/v). The mixture was stirred for 4 h. The potato chip-hexane mixture was filtered with a Whatman No. 2 filter paper (Whatman International Ltd, Maidstone, England). Filtrate was concentrated using a vacuum rotary evaporator (N-1000, Eyela Co., Tokyo, Japan). The extracted oils were stored at -20°C after flushing with nitrogen gas until analyzed further. The oils extracted from the PRCO, PRSO, PPOO, and PVST were abbreviated as RCO, RSO, POO, and VST, respectively.

7. Determination of fatty acid composition of extracted oils

FAME was prepared using BF_3–methanol solution according to AOCS Official Method (2009) Ce 2-66. Fatty acid composition of the extracted oils was determined using gas chromatography (Agilent 6890, Agilent Technologies) equipped with a capillary column (DB-23, 30 m x 0.25 mm x 0.25 μm, J&W Scientific) and a flame ionization detector. Oven temperature increased from 50°C to 160°C at 25°C/min, to 220°C at 4°C/min held for 8 min, and to 250°C at 25°C/min held for 5 min. Injector and detector temperatures were 220 and 260°C, respectively. Split ratio was 1:50.

8. Determination of total polar compounds (TPC), conjugated dienes (CD), peroxide value (PV), *p*-anisidine value (*p*-AV), and total oxidation (Totox) value of extracted oils

TPC were determined using a spectrophotometric method proposed by Xu (2000). The oil extracted from potato chips was placed in a disposable cuvette and warmed in a 60°C for 15 min before measuring the absorbance at 490 nm. TPC were calculated: $y = -2.7865x^2 + 23.782x + 1.039$, where y is TPC (%) in an oil and x is its absorbance. To measure CD, the oil extracted from potato chips was diluted to 1:600 with hexane, measuring spectrophotometrically at 234 nm. An extinction coefficient of 29,000 mol/L was used to quantify the concentration of CD (Saguy and others 1996). Hexane was used as blank. PV and *p*-AV were determined by AOCS Official Method (2009) Cd 8-53 and Cd 18-90, respectively. Totox value is calculated using the equation of $Totox\ value = 2PV + p\text{-}AV$ to estimate the degree of lipid oxidation (Sherwin 1978).

9. Statistical analysis

All determinations except for acrylamides were carried out three times. Statistical analysis using independent t-test and one-way ANOVA ($p<0.05$) was conducted using SPSS 22 software (SPSS Inc., Chicago, IL, USA). Significant differences between means were determined by Duncan's multiple range tests ($p<0.05$).

RESULTS AND DISCUSSION

1. Moisture and crude fat contents in the potato chips

The moisture and crude fat contents in the tested fresh potatoes were 85.1% and 0.8% (dry basis), respectively (Table 1). Moisture significantly decreased after deep-fat frying ($p<0.05$), while crude fat significantly increased to over 20% ($p<0.05$). Moisture and crude fat contents were not significantly different among the potato chips fried in 1, 20, 40, 60, and 80 times repeatedly used oils ($p>0.05$). Repeated use of oils might rarely affect the moisture and oil contents in the fried potato chips.

2. Volatile aldehydes in the potato chips

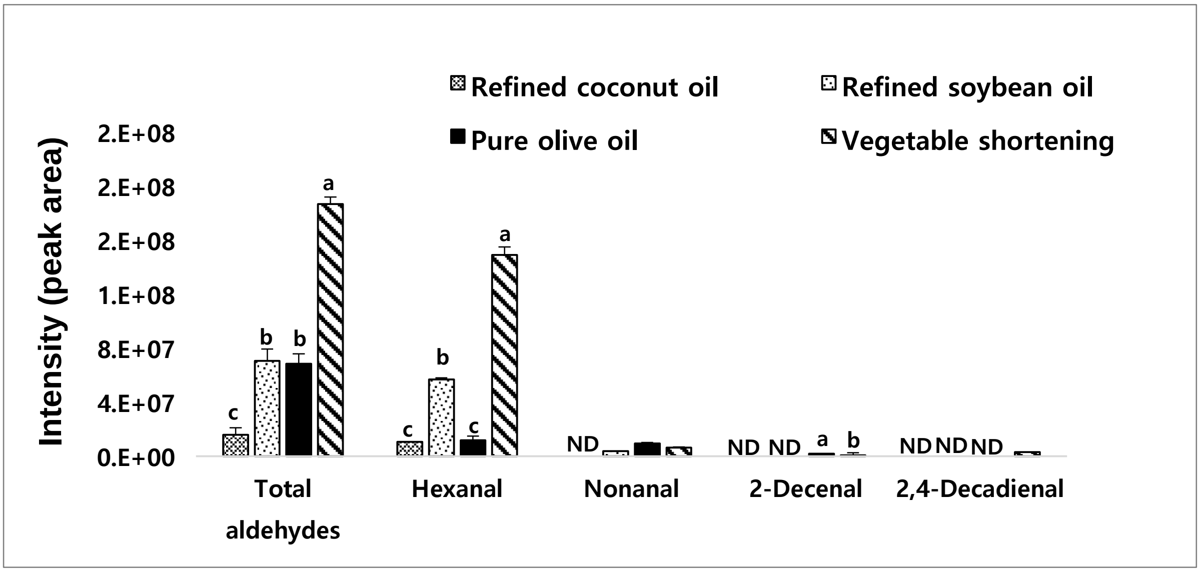
Volatile aldehydes in fresh oils and fresh potatoes were analyzed to compare with those in the fried potato chips. Fresh vegetable shortening was the highest in total aldehydes, followed by fresh refined soybean, pure olive, and refined coconut oils ($p<0.05$; Figure 1A). Fresh vegetable shortening was higher in hexanal than the other fresh oils ($p<0.05$). Fresh pure olive oil was higher in 2-decenal than the other fresh oils ($p<0.05$). Hexanal, 2-decenal, and 2,4-decadienal were detected in fresh potatoes, but nonanal was not (Figure 1B). Previous studies reported that fresh oils and potatoes naturally contained volatile compounds including aldehydes, alcohols, ketones, hydrocarbons, and so on (Karlsson and others 2009), indicating that a part of aldehydes in fried potato chips might come from oils and potatoes. The levels of total aldehydes in the potato chips fried in the first used oils were similar to those in fresh potatoes (Figure 1B and Figure 2). However, the PRCO, PPOO, and PVST fried in 80 times repeatedly used oils were significantly

Table 1. Moisture and crude fat in fresh potato and deep-fat fried potato chips

	Fresh potato	Frying repetition	PRCO	PRSO	PPOO	PVST
Moisture (%)	85.1±3.2	1	62.1±2.0	62.1±4.7	62.5±2.1	63.8±4.4
		20	62.4±1.5	66.7±3.1	65.0±3.2	62.3±7.4
		40	66.2±2.9	68.0±4.0	64.4±3.2	66.0±3.4
		60	64.7±1.3	65.6±1.9	65.6±2.6	62.1±2.1
		80	67.4±4.3	65.3±2.8	62.0±3.3	62.9±2.8
Crude fat (% on dry basis)	0.8±0.5	1	22.2±5.4	22.4±2.4	22.1±3.3	19.7±3.5
		20	25.9±4.7	23.0±3.4	22.6±2.0	25.7±6.5
		40	22.1±0.9	25.6±3.5	26.4±2.4	22.3±2.5
		60	25.4±1.4	24.7±1.4	23.1±1.9	26.1±3.0
		80	24.0±3.9	27.6±4.3	28.0±1.4	23.7±2.6

Values are means and standard deviations (n=3). PRCO, potato chips fried in refined coconut oil; PRSO, potato chips fried in refined soybean oil; PPOO, potato chips fried in pure olive oil; and PVST, potato chips fried in vegetable shortening.

A



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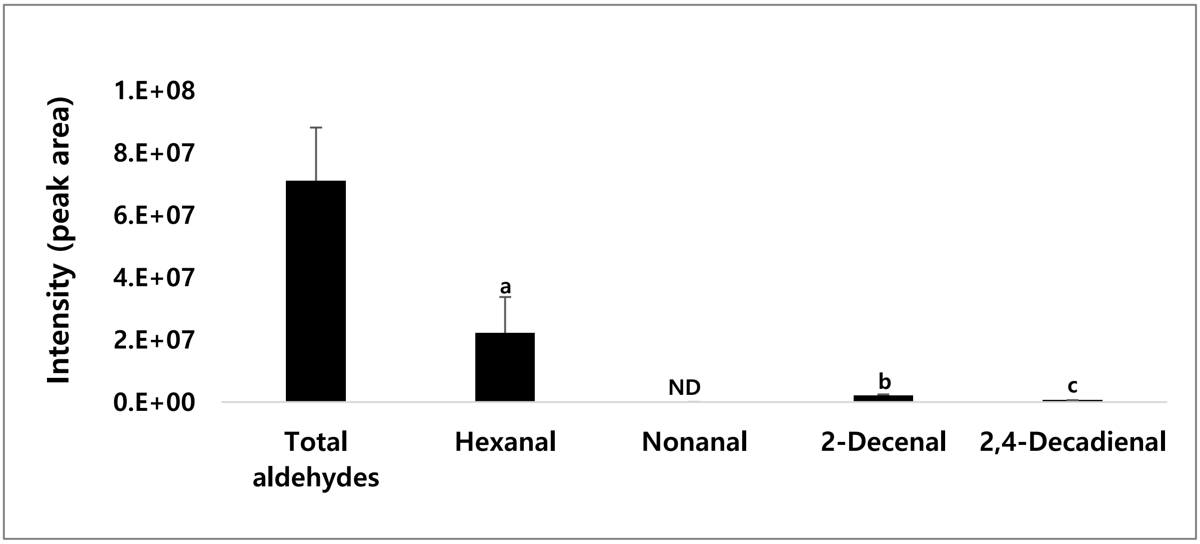

Figure 1. Total aldehydes, hexanal, nonanal, 2-decenal, and 2,4-decadienal in fresh oils (A) and in fresh potatoes (B).

Different letters in (A) indicate significant differences within the same compounds ($p<0.05$; one-way ANOVA and Duncan′s multiple range test). Different letters in (B) indicate significant differences among the aldehydes ($p<0.05$; one-way ANOVA and Duncan′s multiple range test). Bars mean the standard deviations (n=3). ND, not detected.

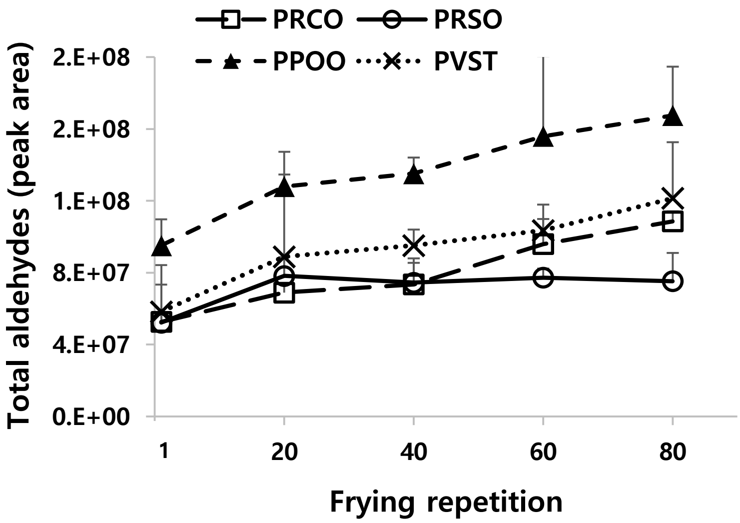

Figure 2. Total aldehydes in the potato chips fried in repeatedly used oils.

PRCO, potato chips fried in refined coconut oil; PRSO, potato chips fried in refined soybean oil; PPOO, potato chips fried in pure olive oil; and PVST, potato chips fried in vegetable shortening. Bars mean the standard deviations (n=3).

higher in total aldehydes than fresh potatoes ($p<0.05$), suggesting more aldehydes might be formed by lipid oxidation during repeated deep-fat frying. The PPOO fried in 1, 40, 60, and 80 times repeatedly used oils were significantly higher in total aldehydes than the other potato chips ($p<0.05$). Fresh pure olive oil had the most unsaturated fatty acids followed by soybean oil, vegetable shortening, and refined coconut oil (Yu 2017). Ramírez and others (2004) also reported that pork loin fried in sunflower and olive oils, which had higher unsaturated fatty acids, showed higher total aldehydes than those fried in butter and pig lard. However, total aldehydes in the PRSO were not higher than in the PVST and PRCO ($p>0.05$).

Contents of hexanal, nonanal, 2-decenal, and 2,4-decadienal in the fried potato chips are shown in Figure 3. The PVST fried in 20, 40, 60 and 80 times repeatedly used oils were higher in hexanal than the other potato chips fried in the corresponding oils, although they were not all significant. This might result from the higher hexanal in the fresh vegetable shortening than those in the other fresh oils (Figure 1A).

Nonanal was higher in the PPOO fried in 1, 20, 40, and 80 times repeatedly used oils than in the other potato chips ($p<0.05$). 2-Decenal was higher in the PPOO fried in 1, 20, and 40 times repeatedly used oils than in the other potato chips ($p<0.05$). Nonanal and 2-decenal are known to be produced from oleic acid by thermo-oxidation (Morales and others 1997). Higher nonanal and 2-decenal in the PPOO might be due to the higher oleic acid in pure olive oil than those in the other oils (Yu 2017). In addition, 2-decenal in the fresh pure olive oil was significantly higher than in the other oils ($p<0.05$) and nonanal in the fresh pure olive oil was higher than in the other oils without significance ($p>0.05$; Figure 1A). Katragadda and others (2010) also reported that extra virgin olive oil constantly heated at 210,

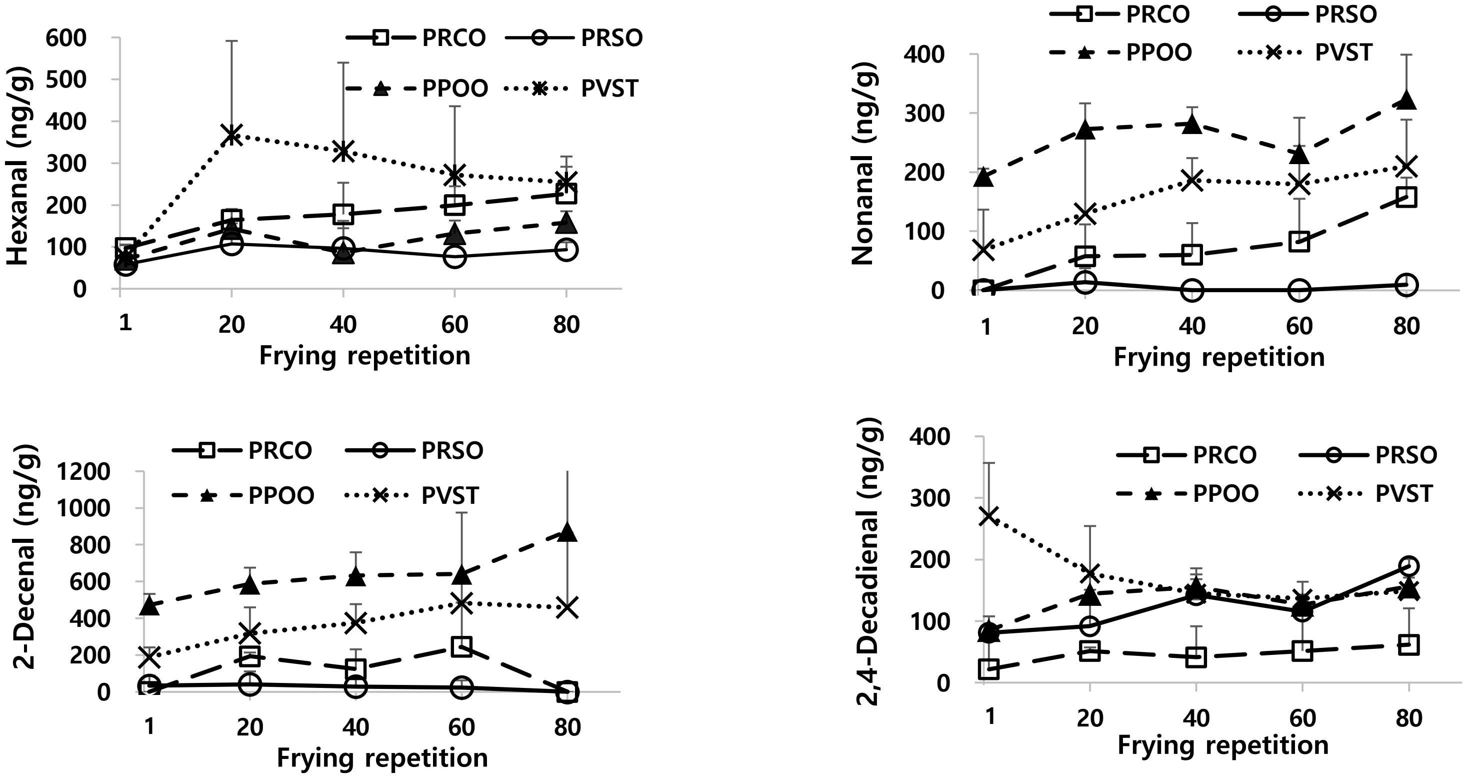

Figure 3. Aldehydes in the potato chips fried in repeatedly used oils.

PRCO, potato chips fried in refined coconut oil; PRSO, potato chips fried in refined soybean oil; PPOO, potato chips fried in pure olive oil; and PVST, potato chips fried in vegetable shortening. Bars mean the standard deviations (n=3).

240, and 270°C had more nonanal and 2-decenal than canola, safflower, and coconut oils.

2,4-Decadienal was more in the PVST fried in the first used oils than in the other potato chips ($p<0.05$). This aldehyde might mostly come from the frying oils considering it was detected in the fresh vegetable shortening, but not in the other oils (Figure 1A). 2,4-Decadienal was lower in the PRCO fried in 40 and 80 times repeatedly used oils than in the other potato chips ($p<0.05$). 2,4-Decadienal is known to be derived by oxidation of linoleic acid (Boskou and others 2006). The lower 2,4-decadeinal in the PRCO might be due to the lower linoleic acid in the refined coconut oil than in the other fresh oils (Yu 2017). This result agrees with a previous study, reporting that palm oil and olive oil, which had lower linoleic acid than sunflower oil, vegetable shortening, and cotton seed oil, showed lower 2,4-decadienal during repeated deep-fat frying (Boskou and others 2006).

Hexanal, nonanal, and 2,4-decadienal have been reported to have cytotoxic effect on human alveolar and lung epithelial cells such as DNA damage, apoptosis, inflammatory, and tumor promotion effects (Choi and others 2013; Cho and others 2014; Loureiro and others 2000; Wu and Yen 2004). Hexanal and 2-decenal have been known to be responsible for off-flavor in cooked foods (Choe and Min 2007). Refined coconut and refined soybean oils might be more suitable for repeated frying than pure olive oil considering the lower levels of 2-decenal, nonanal, and total aldehydes in the PRCO and PRSO.

3. Acrylamides in the potato chips

Acrylamides in the PPOO, PRSO, and PVST did not significantly change as the oils were repeatedly used ($p>0.05$; Figure 4), indicating that lipid oxidation did not

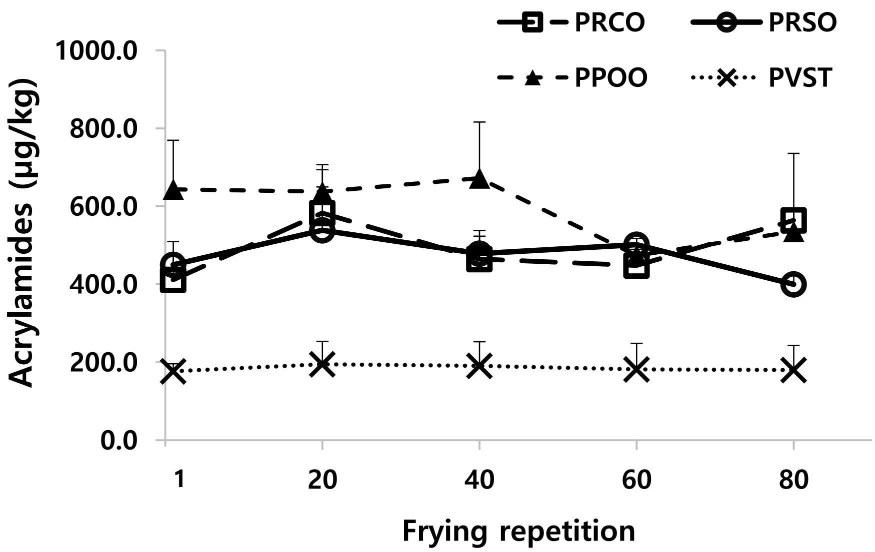

Figure 4. Acrylamides in the potato chips fried in repeatedly used oils.

PRCO, potato chips fried in refined coconut oil; PRSO, potato chips fried in refined soybean oil; PPOO, potato chips fried in pure olive oil; and PVST, potato chips fried in vegetable shortening. Bars mean the standard deviations (n=2).

promote formation of acrylamides. Mestdagh (2007) also reported that acrylamides in French fries fried in soybean oil did not significantly change as oils were repeatedly used. The PVST fried in the 1, 20, 40, and 60 times repeatedly used oils were significantly lower in acrylamides than the other potato chips ($p<0.05$), indicating that the type of oil might affect the acrylamide formation. However, Mestdagh and others (2005) and Williams (2005) could not find any significant association of oil type with acrylamide formation in fried potato chips. It is still controversial whether frying oils have effect on acrylamide production.

4. Fatty acid composition of the extracted oils from fried potato chips

In previous study, fatty acid compositions of fresh oils were analyzed (Yu 2017). Refined coconut oil contained mainly saturated fatty acids (92.0%). Refined soybean oil had predominantly polyunsaturated fatty acids (61.0%) and pure olive oil had mainly monounsaturated fatty acids (75.2%). Saturated fatty acids were 56.0% and monounsaturated fatty acids were 36.1% in vegetable shortening. Fatty acid compositions of the oils extracted from the potato chips fried in the 1 and 80 times repeatedly used oils are shown in Table 2. Saturated fatty acids in the oils extracted from the potato chips fried in the first used oils were higher than those in the fresh oils. It might be because the part of frying oils which had higher saturated fatty acids was more absorbed into the potato chips fried in the first used oils. Fatty acid compositions of the RCO, VST, and POO fried in 80 times repeatedly use oils were little different from those from the potato chips fried in the first used oils. In the RSO, palmitic acid decreased from 18.2% to 14.8%, whereas linoleic acid increased from 48.4% to 52.2% ($p<0.05$). Chen and others (2014) also reported that palmitic acid decreased and linoleic acid increased in chicken fillets fried in

Table 2. Fatty acid compositions of the oils extracted from potato chips (unit: relative area percent)

	RCO		RSO		POO		VST	
Fatty acid	Frying repetition							
	1	80	1	80	1	80	1	80
C12:0	47.1±1.9	46.4±1.4	ND	ND	ND	ND	3.0±0.5	2.4±0.2
C14:0	15.5±0.1	16.1±1.1	ND	ND	ND	ND	2.6±0.5	0.7±1.2
C16:0	7.6±0.2	7.8±0.5	18.2±0.4*	14.8±0.4	17.4±0.9	17.1±1.3	47.1±3.4	49.0±1.9
C18:0	1.3±1.1	1.0±0.9	5.0±0.4	4.7±0.5	2.8±0.5	2.9±1.2	3.8±1.8	3.7±0.8
C18:1	4.8±1.3	4.6±1.6	20.1±0.1	19.6±0.9	67.4±1.0	67.9±1.0	29.4±1.3	29.3±1.3
C18:2	1.6±0.8	1.6±0.8	48.4±0.9	52.2±1.9*	10.7±1.0	11.2±0.6	9.7±0.7	8.4±1.5
C18:3	ND	ND	6.7±0.4	7.2±0.3	ND	ND	ND	ND
∑SFA	92.9±2.4	91.9±3.7	24.7±1.2	21.7±4.2	20.3±1.2	22.0±4.7	60.9±1.9	62.1±2.1
∑MUFA	5.6±1.6	6.0±2.2	20.1±1.1	19.6±0.9	69.0±2.0	67.1±3.8	29.4±1.3	29.4±1.4
∑PUFA	1.6±0.8	1.9±1.3	55.1±1.3	59.4±2.1*	10.7±1.0	11.0±1.0	9.7±0.7	8.4±1.5

Values are means and standard deviations (n=3). Significantly different within the same oil (*$p<0.05$; t-test). ND, not detected; SFA, saturated fatty acids; MUFA, monounsaturated fatty acids; PUFA, polyunsaturated fatty acids; RCO, oil extracted from potato chips fried in refined coconut oil; RSO, oil extracted from potato chips fried in refined soybean oil; POO, oil extracted from potato chips fried in pure olive oil; and VST, oil extracted from potato chips fried in vegetable shortening.

repeatedly used palm oil.

5. Oxidation levels of the extracted oils from fried potato chips

Oxidation levels of oils extracted from fried potato chips are shown in Figure 5. Polar compounds are formed in oils during deep-fat frying due to the decomposition of hydroperoxides to alcohols, ketones, and aldehydes (Rehab and El Annay 2012). TPC in all the oils extracted from the potato chips increased from 1 to 20 times repeated use ($p<0.05$), but did not significantly change after 20 times repeated use ($p>0.05$). Cuesta (1993) also reported that TPC in sunflower oil increased rapidly until 20 times repeated frying, but did not after 30 times. TPC in the RCO (15.0%) was significantly lower than those in the VST (21.2%), RSO (19.3%), and POO (19.3%) comparing at the 80^{th} repetition ($p<0.05$). It has been suggested that the rejection limit of polar compounds in edible oil is around 25% according to several studies (Benedito and others 2007). In this study, all the extracted oils did not exceed the rejection limit during the repeated frying.

Conjugated structures are formed during oxidation, through a shift of a double bond of polyunsaturated fatty acids (Houhoula and others 2002). CD in all the extracted oils continuously increased during the repeated frying ($p<0.05$). CD was the highest in the RSO and the lowest in the RCO at all the repetitions ($p<0.05$). It has been recommended that the frying oil with 29 (Farhoosh and Moosavi 2009) or 44 mmol/L CD (Farhoosh and Tavassoli-Kafrani 2011) should be discarded. CD was the highest in the RSO (24.7 mmol/L) at the 80^{th} repeated use, but did not exceed the suggested rejection level.

PV of the POO and VST rarely changed during the repeated frying. Several studies have reported that PV may not increase continuously, because peroxides are unstable under constant deep-fat frying, decomposing into the ketones, aldehydes,

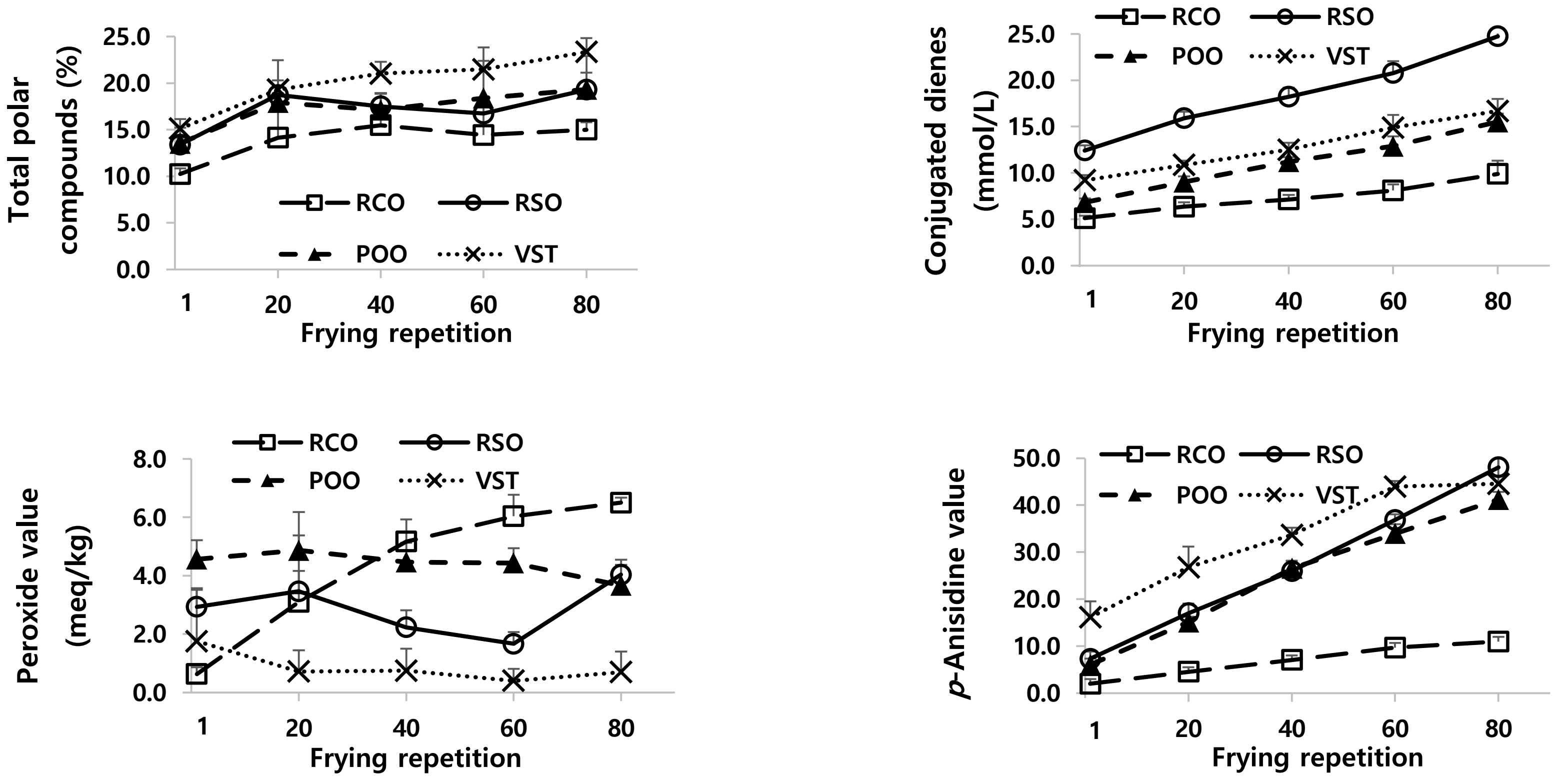

Figure 5. Oxidation levels of the oils extracted from potato chips.

RCO, oil extracted from potato chips fried in refined coconut oil; RSO, oil extracted from potato chips fried in refined soybean oil; POO, oil extracted from potato chips fried in pure olive oil; and VST, oil extracted from potato chips fried in vegetable shortening. Bars mean the standard deviations (n=3).

hydrocarbons, and alcohols (Bešter and others 2008; Karakaya and Şimşek 2011). However, PV of the RCO significantly increased from 0.6 to 6.5 meq/kg during the repeated frying ($p<0.05$). PV of all the oils extracted from the potato chips did not exceed the rejection limits of edible fats and oils (15 meq/kg for virgin oils and cold pressed oils; 10 meq/kg for other fats and oils) suggested by Codex Alimentarius Commission (2015).

p-AV of all the extracted oils significantly increased during the repeated frying ($p<0.05$). *p*-AV of the RCO was lower than those of the other oils at all the repetitions ($p<0.05$), while its PV increased continuously and was significantly higher than those of the other oils at the 60^{th} and 80^{th} repetitions ($p<0.05$), implying that the RCO might be still in the early stage of oxidation during 80 times repeated frying, given PV being a parameter for initial stage of oxidation (Smith and others 2007) and *p*-AV being a parameter for the secondary oxidation products produced by decomposition of peroxides (Tompkins and Perkins 1999).

Totox value (2PV+*p*-AV) is an index to determine the extent of lipid oxidation considering primary and secondary oxidation products. Totox values of all the extracted oils significantly increased during the repeated frying ($p<0.05$; Table 3). Totox value of the RCO was significantly lower than those of the RSO, POO, and VST at all the repetitions ($p<0.05$), which might be due to the lowest unsaturated fatty acids in refined coconut oil (Yu 2017). Choe and Min (2007) reported that oils with higher unsaturated fatty acids degraded faster during repeated frying. Man and Hussin (1998) also reported that coconut oil showed lower Totox value than soybean oil during continuous frying. Totox value of the RSO drastically increased from 13.1 to 56.1 ($p<0.05$), which might be due to the higher linoleic and linolenic acids in refined soybean oil (Yu 2017; Abdulkarim and others 2007). Mariod and

Table 3. Totox values of the oils extracted from potato chips

Frying repetition	RCO	RSO	POO	VST
1	3.3±1.0^{cC}	13.1±2.7^{dB}	15.1±2.5^{eB}	23.9±2.1^{dA}
20	10.7±4.3^{bB}	23.9±7.5^{cA}	24.8±0.9^{dA}	32.1±5.3^{cA}
40	17.3±4.5^{aC}	30.4±1.0^{cB}	35.4±1.9^{cAB}	39.2±3.1^{bA}
60	21.8±4.2^{aC}	40.2±0.5^{bB}	42.9±1.9^{bB}	51.6±1.9^{aA}
80	24.0±2.6^{aC}	56.1±2.2^{aA}	48.5±2.5^{aB}	51.7±5.4^{aAB}

All data represent the means and standard deviations (n=3). Different small letters indicate significant differences within the same columns ($p<0.05$; one-way ANOVA and Duncan's multiple range test). Different capital letters indicate significant differences within the same rows ($p<0.05$; one-way ANOVA and Duncan's multiple range test). RCO, oil extracted from potato chips fried in refined coconut oil; RSO, oil extracted from potato chips fried in refined soybean oil; POO, oil extracted from potato chips fried in pure olive oil; and VST, oil extracted from potato chips fried in vegetable shortening.

others (2006) reported that high-quality oils showed Totox values between 2 and 9, and the values between 10 and 30 are still acceptable for human consumption, but oils with a Totox value higher than 32 should be discarded.

Conclusion

Chemical properties of potato chips fried in repeatedly used oils (refined coconut oil, refined soybean oil, pure olive oil, and vegetable shortening) and oils extracted from the potato chips were investigated. Pure olive oil, which had higher unsaturated fatty acids, produced more aldehydes in the potato chips during the deep-fat frying. Formation of nonanal, 2-decenal, and 2,4-decadienal in the fried potato chips might be affected by the fatty acid composition of frying oils. CD and *p*-AV of all the extracted oils increased during the repeated frying, although they rarely exceeded the acceptable limits until 80 times repeated use of the oils. The RCO, which had higher saturated fatty acids, showed lower TPC, CD, *p*-AV, and Totox value. The PRCO seemed to have better quality than the PRSO, PPOO, and PVST considering aldehydes, TPC, CD, *p*-AV and Totox value. Therefore, refined coconut oil might have better oxidative stability than the other oils during repeated frying.

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국문초록

반복 사용한 기름에 튀긴 감자칩의 화학적 특성

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튀김은 식재료를 고온의 기름에 담가 가열하는 조리법이다. 튀김 조리 시 기름을 반복적으로 사용할 경우 여러 형태의 품질저하 현상이 일어날 수 있으며 그 중에서도 기름의 산화가 촉진되어 여러 지방 산화 물질이 생성될 수 있다. 이러한 물질들은 튀김 조리 시 식품에 직접 흡수되어 품질을 저하시킨다. 따라서 반복 사용할 경우에도 산화 안정성이 높은 튀김 기름을 선택하는 것이 중요하다. 본 연구에서는 상업적으로 많이 사용되며 지방산 조성이 다른 refined coconut oil, refined soybean oil, pure olive oil, vegetable shortening을 튀김유로 선정하였다. 각각의 튀김유 4 L를 튀김기에 넣고 온도가 180±5°C가 되도록 가열한 후, 감자칩을 4분간 튀겨내고 다시 2분간 예비 가열하여 다시 180±5°C가 되도록 하였다. 튀김에 사용한 기름은 80번 반복 사용하였고, 1, 20, 40, 60, 80번째 사용

한 기름에 튀긴 감자칩을 채취하여 분석에 이용하였다. Refined coconut oil, refined soybean oil, pure olive oil, vegetable shortening에 튀긴 감자칩을 각각 PRCO, PRSO, PPOO, PVST로 명명하였고, 각 감자칩에서 추출한 기름은 RCO, RSO, POO, VST로 명명하였다. 튀기기 전의 감자와 비교하였을 때, 튀김 후 감자칩의 수분 함량은 유의적으로 적었고, 조지방 함량은 유의적으로 많았다($p<0.05$). 튀긴 감자칩의 수분 함량과 조지방 함량은 기름의 반복 사용 횟수에 대해서는 유의적인 차이가 없었다($p<0.05$). 서로 다른 기름에 튀긴 감자칩을 비교하였을 때, 총 휘발성 알데하이드는 1, 40, 60, 80번째 반복 사용 기름에 튀긴 PPOO에 유의적으로 많았다($p<0.05$). 알데하이드 중 nonanal과 2-decenal은 1, 20, 40번째 반복 사용 기름에 튀긴 PPOO에 유의적으로 많았다($p<0.05$). 아크릴아마이드는 1, 20, 40, 60번째 반복 사용 기름에 튀긴 PVST에 유의적으로 적었다($p<0.05$). 감자칩에서 추출한 기름의 산화 안정성을 분석한 결과, 모든 추출 기름의 total polar compounds (TPC)는 20번째 반복 사용할 때까지 유의적으로 증가하였으나($p<0.05$), 그 이후는 거의 변하지 않았다. RCO의 TPC는 다른 추출 기름에 비해 유의적으로 적었다($p<0.05$). 모든 추출 기름의 conjugated dienes (CD)는 유의적으로 증가하였고, RCO의 CD가 다른 추출 기름들 중 가장 적었다($p<0.05$). RCO의 peroxide value (PV)는 유의적으로 증가하였으나($p<0.05$), POO와 VST의 PV는 거의 변화가 없었다($p>0.05$). RCO의 *p*-anisidine value (*p*-AV)가 다른 추출 기름에 비해 가장 낮았다($p<0.05$). 모든 추출 기름의 total oxidation (Totox) value는 유의적으로 증가하였고($p<0.05$),

추출 기름 중 RCO의 Totox value가 가장 낮았다($p<0.05$). 감자칩의 휘발성 알데하이드와 감자칩에서 추출한 기름의 TPC, CD, *p*-AV, Totox value를 기준으로 판단하였을 때 PRCO의 품질이 가장 좋았다. 따라서, 산화 안정성 측면에서 refined coconut oil이 다른 세 기름에 비해 튀김유로서 보다 더 적합하다고 생각한다.

주요어: 튀김; 튀김유; 감자칩; 알데하이드; 추출 기름; 산화 안정성

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