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Effect of Roasted Sesame Oil on Qualitative Properties of Frying Oil during Deep-Fat Frying

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ABSTRACT

In this study, sesame seed was firstly roasted at 216.8°C for 19.3 minutes and its oil was then extracted. Commercial Frying Oil (CFO) was blended by 10, 20, and 30% Roasted Sesame Oil (RSO) and used in deep-fat frying to prepare potato chips. The process was performed daily at 180°C for 1 hour, in five consecutive days. Frying performance of the oils was evaluated by the measurement of parameters such as peroxide value, Oxidative Stability Index (OSI), Total Polar Compounds (TPC) and fatty acids profile. The results showed that roasting had a great positive influence on phenolic compounds content (21 times) and oxidative stability (3.6 times) of sesame oil. During frying, the level of TPC increased significantly as an increasing rate of 27, 22, 21, 23.2, and 29% was obtained for RSO-10%, RSO-20%, RSO-30%, CFO-Tert-ButylHydroQuinone (TBHQ), and CFO, respectively. The *OSI* significantly decreased and, in the fifth day of frying, CFO-TBHQ had the highest *OSI* of 10.6 hours followed by RSO-30% (8 hours). By increment in RSO concentration, the antioxidant capacity of frying oils was elevated, although commercial frying oil containing TBHQ exhibited higher activity than RSO-30%.

Keywords: Antioxidant, OSI, Phenolic compounds, Polar compounds, Tert-butylhydroquinone.

INTRODUCTION

Frying is one of the oldest processes to prepare foods such as meat, fish, and vegetables (Velasco *et al*., 2009). During frying, foods absorb an appreciable amount of the oil (up to 40% of fried food), so the frying oil quality is a major factor in quality and nutritional value of fried products (Houhoula and Oreopoulou, 2004; Mallikarjunan *et al.,* 2010). Since frying is usually conducted at high temperatures (180-200 °C), both oil oxidation and hydrolysis could take place during the frying operation (Stier, 2001). Usually, tocopherols present in the vegetable oils are sufficient to protect them against oxidation at environmental temperature. However, at high temperature of deep-fat frying, antioxidants with high efficiency are required to delay oil degradation. Therefore, synthetic antioxidants such as Butylated HydroxyAnisole (BHA), Butylated HydroxyToluene (BHT) and Tert-ButylHydroQuinone (TBHQ) are commonly used in commercial frying oils (Awashti, 2000). Recent studies have shown that these compounds might have several adverse effects on human health and cause some diseases like cancer (Barlow, 1990). Thus, finding a novel natural alternative antioxidant could be important to deal with the problem (Shahidi, 1997). Salih AL-Janabi *et al*. (2013) introduced squeezed grapes residue as a natural antioxidant in frying oil. They observed that the antioxidant activity of grapes pomace was similar to BHT. It is also reported that eggplant peel extract play a key

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role in enhancement of the oxidative stability of sunflower oil during deep-fat frying (Basuny *et al*., 2013). Moreover, Jaswir *et al*. (2000) found that rosemary and sage oleoresins could be effective antioxidants protecting refined bleached deodorized palm olein against oxidative deterioration during frying.

Sesame seed (*Sesamum indicum* L.) is one of the main oil seeds and contains more than 40% oil. Sesame oil requires little or no winterization and can be used directly without refining (Fukuda *et al.,* 1986). Some health beneficial functions such as decreasing blood lipids and arachidonic acid level, estrogenic activity, providing anti-inflammatory functions, exhibiting antimutagenic activity, increasing antioxidant ability and γ-tocopherol bioavailability are reported for sesame oil (Wu, 2007; Fukuda *et al*., 1986). High oxidative stability of sesame oil compared with other vegetable oils is due to the large quantity of endogenous antioxidants (Yoshida and Takagi, 1997). Sesame oil could be used in either food or cosmetic products due to its high oxidative stability and other favorable properties (Borchani *et al.,* 2010). It is demonstrated that the antioxidant activity of both roasted and unroasted sesame oils were remarkably higher than other common vegetable oils (Hemalatha and Ghafoorunisa, 2007). A rapid increase in oxidation rate was shown in soybean and rapeseed oils while both roasted and unroasted sesame oils were very stable during storage in an open dish at 60°C (Fukuda and Namiki, 1988). Before oil extraction, seed roasting improves sesame oil yield and quality (Akinoso *et al*., 2010). Roasted sesame oil is more stable to oxidation than unroasted type because of increment in concentration of lignans compound (Kim, 2000, Hassanein, 2010). Extremely high oxidative resistance of roasted sesame oil is associated with the presence of lignans such as sesamolin and sesamin, sesamol, tocopherols and Maillard reaction products (Lee *et al.*, 2010).

The objectives of the present study were: (1) To evaluate the effect of roasting process on sesame oil characteristics; (2) To apply Roasted Sesame Oil (RSO) as a source of natural antioxidants at different concentrations into commercial frying oil to conduct a five-day intermittent frying, and (3) To evaluate the effect of frying cycles on the chemical (free fatty acid content, peroxide, anisidine, totox and conjugated diene values, oxidative stability, fatty acids composition and Total Polar Compounds (TPC) content, and phenolic compounds content) and physical (color) properties of RSO-enriched frying oil during the process.

MATERIALS AND METHODS

Materials

Brown sesame seeds (*Sesamum indicum*, L.) were purchased from local market. Commercial frying oil (consisting of 50% sunflower oil and 50% palm olein) without any antioxidant was supplied from Nahangol vegetable oil factory (Brujen, Iran). A variety of potato, Agria, was prepared from Garmabad (Isfahan, Iran). All solvents and chemicals used were of analytical grade and obtained from Merck Company (Darmstadt, Germany).

Preparation of Roasted Sesame Oil

Sesame seed was firstly cleaned, washed and dried at room temperature. The seeds were roasted at 216.8°C for 19.3 minutes using Binder® heating oven (model FD 115, 600×480×410 mm, Germany) with free air circulation. The roasting condition was obtained in pretests considering the color and stability of roasted sesame oil, as responses, using Response Surface Methodology (RSM) (Borjian *et al.,* 2015). The roasted sesame seeds were finally pressed using Oil-Love instrument (model SE-6, Korea) to obtain Roasted Sesame Oil (RSO). To remove fine particles, the oil was finally centrifuged (model Nuve, NF2000, Turkey) at 4,500 rpm for 10 minutes.

Frying Oils Formulation

Roasted Sesame Oil (RSO) was blended into commercial frying oil (without any added natural or synthetic antioxidant) at concentrations of 10, 20 and 30% (w/w). One sample of commercial frying oil containing only 70 ppm TBHQ was also used as commercial frying oil. The control sample was the frying oil.

Preparation of Potato Slices and Frying Condition

In order to prepare slices, potatoes were washed, peeled, and sliced. The blanching of the slices was performed in hot water at 85°C for 3.5 minutes. They were then dried to moisture content of 60% at room temperature and normal air flow. Each oil sample, about 1.5 L, was placed in a deep rotary fryer with 1.5 L capacity. The batches of potato slices (30 g) were put into the hot oil (175±5°C) and fried for 3 minutes. Total time of frying process for each oil sample was one hour a day for ten batches. In purpose of reusing the oil next day, it was collected, cooled and stored in a dark and cool place. The procedure was continued for five sequential days and oil sampling was carried out in all five days of frying. Right after sampling, the oil was frozen and stored under a nitrogen atmosphere at -18°C to prevent changes in its chemical composition.

Chemical and Physical Analysis of RSO and Frying Oils

The methods described by American Oil Chemists' Society (AOCS, 2004) were used for determination of the peroxide value (Cd 8-53), free fatty acids content (Cd 3d-63), anisidine value (Cd 18-90), Oxidative Stability Index (OSI) (Cd12b-92) and diene conjugates content (Ch 5-91). Total polar compounds were determined using the method developed by Schulte (Schulte, 2004). Oil color in terms of Hunter Lab values (L*, a*, b*) was determined using Lovibond® Tintrometer (Model PFXi-995, UK). Total phenolic compounds content was measured using Folin-Ciocalteau reagent as described by Capannesi *et al*. (2000). A calibration curve was constructed using methanolic solutions containing gallic acid at concentrations between 0.04 and 0.7 mg mL^{-1} (y= 0.0011x+0.1494).

Fatty Acids Profile

Fatty acids profile was determined using gas chromatography (Youngling Acme 6000 series, Korea). The fatty acid methylation was carried out according to the AOAC method (969/33). Fatty acid methyl esters were separated on a CPSIL 88 (50 m×0.25 mm×0.2 µm) capillary column fitted with Flame Ionization Detector (FID) according to the AOCS method (Ce 1e- 91). The carrier gas, Helium, was used at a flow rate of 0.8 mL min^{-1}. Column temperature was fixed at 175°C. Detector and injector temperatures, injection volume and split ratio were 260°C, 250°C, 1 µL and 1:100, respectively.

Statistical Analysis

All determinations were accomplished in duplicate and data were subjected to Analysis Of Variance (ANOVA) using SAS software (version 9.1.3). The Least Significant Difference (LSD) was performed to evaluate means at significance level of 95%.

RESULTS AND DISCUSSION

Roasting Effect on Sesame Oil Characteristics

Roasting process affected chemical and physical properties of sesame oil. As shown in Table 1, Free Fatty Acid (FFA) percentage increased significantly after roasting process.

However, FFA content was lower than the minimum acceptable value of 0.21% recommended for sesame oil by the Codex Alimentarius Commission (Abayeh *et al*., 1998). Abou-ghariba *et al*. (2000) found that FFA was significantly increased in sesame seed oil with roasting process. The increase in FFA of the oil might be attributed to thermal decomposition of TriAcylGlycerol (TAG). During roasting, Peroxide Value (PV) was also insignificantly increased because of high temperature of the process. It was observed that *PV* increased slightly from 0.16 to 0.19 meq O_2/kg oil, which might be because the lipid oxidation occurred throughout roasting (Table 1).

L^* value of oil color significantly decreased while a^* and b^* values increased over roasting (Table 1). This means that roasting process caused an increase in the dark, red, and yellow units of oil color. This can be due to the browning reactions (such as Maillard reaction and caramelization), oxidation, phospholipids degradation, polymerization and other chemical changes occurring at the high temperature of the process (Manzocco *et al.,* 2000). Some products originating from TriAcylGlycerol (TAG) oxidation are polar compounds. Moreover, the products of browning reactions, which would accelerate at temperatures above 180°C, are also kind of polar compounds (Lee *et al*., 2004). This might be the reason that polar compounds increased from 7% in sesame oil to 12% in roasted type during roasting (Table 1).

After roasting process, total phenolic compounds of sesame oil were considerably increased 20.8 times (Table 1). In plants, phenolic compounds are naturally present in bound form and roasting at high temperature could lead to cleave and release of phenolic compounds (Jeong *et al.,* 2004). Farhoosh *et al*. (2013) found that sesame oil had the highest content of total tocopherols and phenolic compounds among three antioxidative oils; sesame seed, rice bran, and bene hull oils. Jannat *et al*. (2010) observed an increase of 82% in phenolic content of sesame seed after roasting process. It is reported that sesamol, a potent phenolic antioxidant, increased over roasting process (Yoshida and Takagi, 1997). In fact, total phenolic compounds content in seed oils is an important factor because this parameter is well correlated with oil shelf-life and particularly its resistance to oxidation (Cheikh-Rouhou *et al*., 2006). As expected, roasting resulted in a marked increase (about 3.6 folds) in oil stability and the *OSI* was elevated from 10 hours in sesame oil to 36 hours in RSO (Table 1). Kim (2000) has reported that roasted sesame oil had greater storage stability than unroasted ones. The relatively high oxidation stability of RSO may have resulted from increment in total phenolic compounds content and the production of antioxidants like sesamol and sesaminol and other compounds such as sesamin and sesamolin over roasting process. A study showed that sesamol greatly prevented thermal decomposition of methyl linoleate (Lee and Choe, 2008). It is also reported that seed roasting affected total

Table 1. Chemical and physical properties of crude and roasted sesame oil.[a]

	Sesame oil	Roasted sesame oil
Free fatty acid (% as oleic acid)	0.10±0.00[a]	0.13±0.00[b]
Peroxide value (meq O_2/kg oil)	0.16±0.00[b]	0.19±0.02[a]
Color value *L**	87.76±0.91[a]	39.96±0.07[b]
Color value *a**	-6.51±0.19[b]	24.86±0.02[a]
Color value *b**	20.61±0.13[b]	28.94±0.20[a]
Phenolic compounds (%, As gallic acid equivalent)	0.035±0.00[b]	0.73±0.00[a]
Total polar compounds (%)	7±0.00[b]	12±0.00[a]
Oxidative stability index at 110°C (h)	10.03±0.07[b]	36.28±0.19[a]

[a] Means within a row with different letters are significantly different (P< 0.05).

phenolic levels of sesame oil as well as almond oil. The changes in TPC led to the changes in antioxidant activities of seed oils (Lin *et al.,* 2016).

Frying Performance of the Oils with RSO

Free Fatty Acids Content

Figure 1 shows FFA percentage in the blends during five-day frying. FFA index, as an indicator of oil quality, can lead to unpleasant taste and flavor in oils and fried products. However, it is not a reliable parameter for evaluation of frying oil degradation, because FFAs formed due to oil hydrolysis could be volatilized and converted to other decomposition products (Manzocco *et al*., 2001). FFA content in fresh oils ranged from 0.04-0.14% as the control and RSO-30% frying oils had the lowest and highest level of FFA, respectively. Since RSO contained 0.13% FFA, by increment in RSO content, the FFA percentage of fresh frying oils has been also increased. The FFA content of the blends increased gradually over 5 days of frying ($P< 0.05$). Hydrolysis, the major chemical reaction during deep frying, occurs when food is fried in hot oil. In the presence of food moisture, as steam or water, triglycerides are hydrolyzed to FFA, monoglycerols, diglycerols and glycerol (Abou-ghariba *et al.,* 2000).

Peroxide, Anisidine and Totox Values

Table 2 represents peroxide, anisidine and totox values of the oil blends over frying days. Hydroperoxides, the primary products of lipid oxidation, are unstable compounds formed from fatty acids throughout oil oxidation. In all oil samples, the peroxide

Table 2. Changes in peroxide, anisidine and Totox values of different oil blends during frying.[a]

	Day	CFO [b]	CFO+10%RSO [c]	CFO+20%RSO [d]	CFO+30%RSO [e]	CFO+TBHQ [f]
PV (meq O_2/kg oil)	0	0.00 ± 0.00^{Fd}	0.18 ± 0.00^{Ec}	0.24 ± 0.03^{Fb}	0.42 ± 0.01^{Ea}	0.00 ± 0.00^{Dd}
	1	5.43 ± 0.29^{Aa}	4.36 ± 0.10^{Bb}	2.56 ± 0.05^{Ac}	1.74 ± 0.03^{Cd}	2.78 ± 0.03^{Bc}
	2	4.12 ± 0.03^{Bb}	4.69 ± 0.02^{Aa}	2.4 ± 0.01^{Bd}	2.04 ± 0.01^{Be}	3.21 ± 0.04^{Ac}
	3	2.65 ± 0.06^{Db}	4.40 ± 0.03^{Ba}	2.04 ± 0.04^{Cc}	2.71 ± 0.15^{Ab}	2.69 ± 0.02^{Bb}
	4	3.58 ± 0.03^{Cb}	3.73 ± 0.02^{Ca}	0.77 ± 0.02^{Ee}	1.11 ± 0.08^{Dd}	2.37 ± 0.07^{Cc}
	5	2.13 ± 0.17^{Ea}	2.36 ± 0.04^{Da}	1.03 ± 0.08^{Db}	0.99 ± 0.04^{Db}	2.10 ± 0.27^{Ca}
AV [g]	0	10.28 ± 0.32^{Fc}	10.85 ± 0.09^{Fb}	11.00 ± 0.14^{Fb}	11.97 ± 0.14^{Fa}	10.17 ± 0.08^{Fc}
	1	16.82 ± 0.08^{Eb}	19.46 ± 0.81^{Ea}	16.87 ± 0.98^{Eb}	16.26 ± 0.13^{Eb}	12.26 ± 0.24^{Ec}
	2	23.32 ± 0.03^{Dc}	28.84 ± 0.57^{Da}	24.36 ± 0.24^{Db}	21.76 ± 0.45^{Dd}	16.26 ± 0.15^{De}
	3	28.31 ± 0.32^{Cc}	38.56 ± 0.14^{Ca}	29.21 ± 0.16^{Cb}	28.24 ± 0.43^{Cc}	20.44 ± 0.02^{Cd}
	4	35.05 ± 0.60^{Bb}	46.08 ± 0.40^{Ba}	34.28 ± 0.74^{Bbc}	33.39 ± 0.29^{Bc}	25.96 ± 0.34^{Bd}
	5	40.83 ± 0.02^{Ab}	52.21 ± 0.09^{Aa}	38.72 ± 0.31^{Ac}	38.47 ± 0.15^{Ac}	31.09 ± 0.05^{Ad}
Totox	0	10.28 ± 0.32^{Fc}	11.21 ± 0.09^{Fb}	11.49 ± 0.07^{Fb}	12.81 ± 0.17^{Fa}	10.17 ± 0.08^{Fc}
	1	27.68 ± 0.67^{Ea}	28.19 ± 0.60^{Ea}	21.99 ± 0.87^{Eb}	19.75 ± 0.06^{Ec}	17.83 ± 0.28^{Ed}
	2	31.57 ± 0.10^{Db}	38.23 ± 0.53^{Da}	29.16 ± 0.26^{Dc}	25.94 ± 0.62^{Dd}	22.68 ± 0.07^{De}
	3	33.62 ± 0.45^{Cb}	47.38 ± 0.04^{Ca}	33.30 ± 0.07^{Cb}	33.66 ± 0.12^{Cb}	25.83 ± 0.07^{Cc}
	4	42.22 ± 0.67^{Bb}	53.54 ± 0.34^{Ba}	35.83 ± 0.70^{Bc}	35.61 ± 0.46^{Bc}	30.70 ± 0.48^{Bd}
	5	45.10 ± 0.32^{Ab}	56.93 ± 0.01^{Aa}	40.78 ± 0.14^{Ac}	40.45 ± 0.24^{Ac}	35.30 ± 0.49^{Ad}

[a] A-F: Means within a column with different letters are significantly different ($P< 0.05$). a-f: Means within a row with different letters are significantly different ($P<0.05$). [b] Commercial Frying Oil; [c] Commercial Frying Oil+10% roasted sesame oil; [d] Commercial Frying Oil+20% roasted sesame oil; [e] Commercial Frying Oil+30% roasted sesame oil; [f] Commercial Frying Oil+Tert-ButylHydroQuinone, [g] p-Anisidine Value.

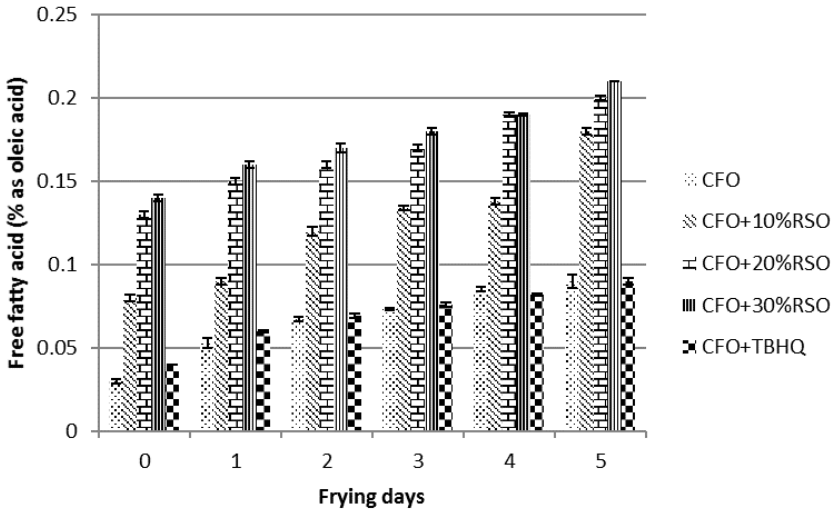

Figure 1. Free fatty acids content of frying oils during five consecutive frying days. CFO; CFO+10%RSO; CFO+20%RSO; CFO+30%RSO, and CFO+TBHQ are defined in the text and under Table 2.

value was increased during the first two days of frying and then decreased over third and fourth day of frying. An initial sharp increase in *PV*s was observed in which the highest and lowest values belonged to the control (5.34) and RSO-30% (2.04 meq O_2/kg) samples, respectively ($P< 0.05$). During frying, a fluctuation in peroxide value of the blends was observed which can be due to the fact that hydroperoxides are unstable under frying temperature and decompose while they are formed due to oil oxidation (Debnath *et al*., 2012).

Therefore, complementary Anisidine Value (AV) measurement was also conducted to determine the amount of aldehydic secondary oxidation products, which can be used as marker to determine the degree of hydroperoxides degradation. *AV* was increased significantly ($P< 0.05$) in all oil samples over frying. At the end of the process, the sample containing 10% roasted sesame oil showed the highest value of *AV*, whereas the lowest value belonged to commercial sample containing synthetic antioxidant. Since the measurement of primary and secondary oxidation products is not alone reliable, totox value (2 PV+AV) was used to show both post and future degradation profile of each sample. The lower the totox value, the better the oil quality (Kim, 2000). The totox value was increased significantly in all oil samples during five-day frying. The commercial sample showed the lowest and the sample containing 10% had the highest totox value at fifth day of frying. At the final day, totox value of CFO, RSO-10%, RSO-20%, RSO-30% and CFO-TBHQ reached 45.10, 56.93, 40.78, 40.45, and 35.30, respectively. The results showed that TBHQ, a strong synthetic antioxidant, was the most effective additive to reduce oil oxidation. Totox value was decreased with increase in RSO percentage, implying that RSO has an antioxidant activity and protective effect against hydroperoxides formation and decomposition. The control sample showed lower value than that of the oil containing 10% RSO, while the blends containing 20 and 30% RSO possessed higher oxidative stability than that of the control sample (Table2).

Conjugated Diene Value (CDV)

The changes in *CDV* of oil blends over frying are shown in Figure 2. During oil oxidation, reaction of non-conjugated double

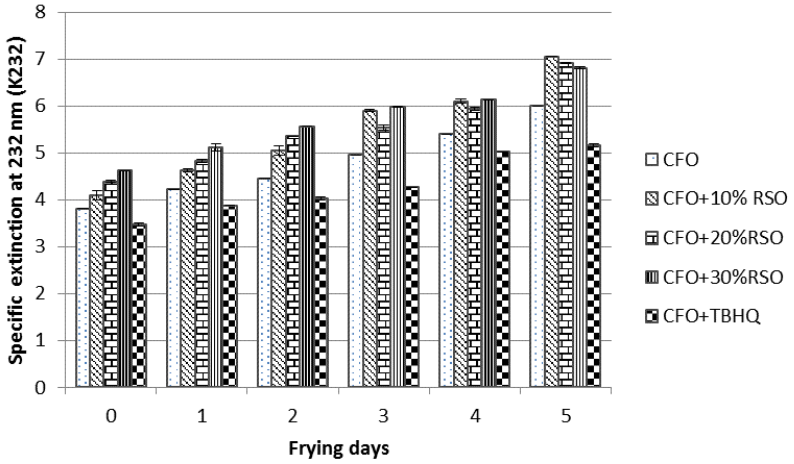

Figure 2. Changes in conjugated dienes content (K232) of frying oils during five consecutive frying days. CFO; CFO+10%RSO; CFO+20%RSO; CFO+30%RSO, and CFO+TBHQ are defined in the text and under Table 2.

bonds of linoleic acid with oxygen produces more resistant conjugated ones which can be used to measure oil oxidation (Koh *et al.,* 2011). In fresh oils, by increase in content of RSO, the *CDV* was increased, which might be due to the presence of conjugated dienes in RSO resulting from roasting process. All samples showed a significant increase in *CDV* during five-day frying. Although the sample with TBHQ had the lowest value (5.16%) at the end of the process, RSO-30% exhibited the lowest increment rate (47.4%). Jeong *et al.* (2004) indicated that the use of sesame lignans, as natural antioxidants, led to a reduction in production of conjugated dienes. Lee *et al*. (2010) also showed that sesamol, abundant in roasted sesame oil, had an antioxidant capacity similar to TBHQ and reduced *CDV* in sesame pressed oil and lard.

Total Polar Compounds (TPC) Content

Once oil is exposed to frying condition, polar compounds such as short chain fatty acids, aldehydes and ketones are produced. Thus, the measurement of TPC is the most important and reliable test for evaluating oil degradation. Many European countries have established that the level of 25-27% TPC is the threshold point for discarding heated cooking oil (Koh *et al.,* 2011). Figure 3 shows the percentage of polar compounds in the frying oils over the process. Since RSO contained 12% TPC (Table 1), it was observed that by increment in RSO content, TPC level of fresh frying oils has been also increased ($P< 0.05$). TPC level increased significantly throughout the five consecutive days of frying. In the last day, the range of TPC level was 10.5-11.5 and an increase rate of 27, 22, 21, 23.2, and 29% was obtained for RSO-10%, RSO-20%, RSO-30%, CFO-TBHQ, and CFO, respectively.

Color

Table 3 shows the color changes of the oil samples during five-day frying. Frying oil color has been usually used as a tool to evaluate the oil quality; however, it has not been found to be an effective index for oil discard. As previously discussed, roasting process made sesame oil to be darker in color. Therefore, addition of RSO in fresh blends caused a marked decrease in L^* and increase in a^* and b^* values, as RSO-30% had the lowest L^* (68.5) and highest a^* (5.4) and b^* (41.6) values. Over frying, all

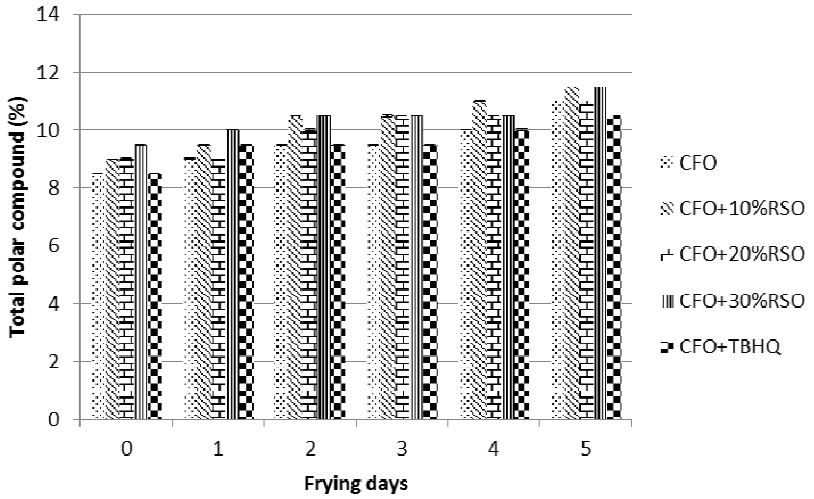

Figure 3. Changes in total polar compounds content of frying oils during five consecutive frying days. CFO; CFO+10%RSO; CFO+20%RSO; CFO+30%RSO, and CFO+TBHQ are defined in the text and under Table 2.

Table 3. Color changes of the frying oils over five consecutive frying days.[a]

Color values	Day	CFO[b]	CFO+10%RSO[c]	CFO+20%RSO[d]	CFO+30%RSO[e]	CFO+TBHQ[f]
*L**	0	91.83 ±0.05^{bA}	82.66 ±0.11^{cA}	75.24 ±0.03^{dA}	68.59 ±0.08^{eA}	92.51 ±0.04^{aA}
	1	91.51 ±0.18^{aAB}	80.68 ±0.71^{bB}	72.53 ±0.32^{cB}	62.84 ±0.03^{dB}	91.71 ±0.08^{aB}
	3	91.01 ±0.04^{aB}	79.68 ±0.56^{bC}	71.91 ±0.10^{cC}	62.44 ±0.29^{dB}	91.26 ±0.10^{aB}
	5	90.31 ±0.02^{aC}	77.53 ±0.54^{bD}	69.38 ±0.03^{cD}	60..96 ±0.12^{dC}	90.25 ±0.05^{aC}
*a**	0	-9.90 ±0.01^{dD}	-6.21 ±0.02^{cD}	-0.36 ±0.01^{bD}	5.40 ±0.02^{aD}	-9.92 ±0.03^{dD}
	1	-9.47 ±0.05^{dC}	-5.08 ±0.13^{cC}	1.85 ±0.07^{bC}	8.79 ±0.02^{aC}	-9.59 ±0.03^{eC}
	3	-9.02 ±0.02^{dB}	-4.70 ±0.02^{cB}	2.03 ±0.03^{bB}	9.47 ±0.01^{aB}	-9.19 ±0.03^{eB}
	5	-8.72 ±0.01^{dA}	-3.91 ±0.05^{cA}	3.16 ±0.02^{bA}	10.44 ±0.03^{aA}	-8.92 ±0.06^{eA}
*b**	0	19.81 ±0.01^{dD}	33.72 ±0.02^{cD}	41.14 ±0.01^{bA}	41.67 ±0.03^{aA}	19.82 ±0.23^{dD}
	1	22.38 ±0.01^{dC}	35.98 ±0.33^{cC}	40.60 ±0.33^{aB}	39.42 ±0.45^{bB}	21.96 ±0.02^{eC}
	3	24.36 ±0.01^{dB}	36.57 ±0.02^{cB}	40.66 ±0.16^{aB}	39.01 ±0.03^{bC}	22.37 ±0.01^{eB}
	5	24.90 ±0.01^{dA}	37.01 ±0.37^{cA}	39.82 ±0.02^{aC}	38.44 ±0.16^{bD}	24.25 ±0.03^{eA}

[a] A-D: Means within a column with different letters are significantly different (P< 0.05). a-e: Means within a row with different letters are significantly different (P<0.05). [b] Commercial Frying Oil; [c] Commercial Frying Oil+10% roasted sesame oil; [d] Commercial Frying Oil+20% roasted sesame oil; [e] Commercial Frying Oil+30% roasted sesame oil; [f] Commercial Frying Oil+Tert-ButylHydroQuinone,.

samples experienced a decrease in Lightness index (L^*) while an increase in the redness index (a^*) was observed. Darkening might be due to the solubilization of unsaturated carbonyl compounds or non-polar compounds from foodstuff into the oil. Also, changing the oil color to red (increase in a* value) can be loosely correlated to combined oxidized fatty acids and pyrolytic condensation products which were created during frying condition (Stier, 2001; Lalas, 2008). The *b** value for the samples of the control, commercial, and RSO-10% increased during frying, whereas it decreased for the samples containing 20 and 30% RSO. Oil yellowness is usually attributed to combined hydroperoxides and aldehydes and can increase with progress in oil oxidation (Lalas, 2008). It seems that addition of RSO-20% and RSO-30% could

prevent oil oxidation and led to lower *b** value of oil color compared to other treatments.

Oil Stability Index

Figure 4 shows the changes in *OSI* of oil samples over five-day frying. Before frying, the blends with higher content of RSO showed higher stability, although the oil containing TBHQ had the highest stability of 19.3 hours (two times higher than that of the control sample). In all samples, *OSI* significantly decreased during frying. Although the commercial oil with TBHQ had the best oxidative stability in the fifth day of frying, the blends containing RSO represented lower reduction rate.

Fatty Acid Composition

Fatty acid composition of the oil affects its nutritional value and oxidative stability (Debnath *et al*., 2012). Table 4 shows the fatty acid composition in the blends over five days of frying. In the fresh control, the main fatty acids were oleic, linoleic, palmitic and stearic acids, respectively. By higher content of RSO, the fresh blends showed a decrease in C16, but a slight increase in C18:0, C18:1 and C18:2. Frying process led to reduction in linoleic and oleic acids content, but increased the amount of saturated fatty acids, probably because of unsaturated fatty acids oxidation, which occured in all samples. Frying usually results in changes in unsaturated fatty acids and slight increase in saturated types (Alireza *et al.,* 2010).

CONCLUSIONS

In this work, the findings revealed that roasting process caused a remarkable increment in total phenolic compounds content of sesame oil and resulted in its higher oxidative stability. The addition of roasted sesame oil, as a natural source of antioxidants, to frying oil prolonged its heat stability and shelf life, although TBHQ, as a strong synthetic antioxidant, showed higher antioxidant capacity compared to RSO added at maximum concentration (30% w/w) to the oil. It is observed that heat stability of the oil containing RSO at 10% was lower than that of the control sample which might be due to the presence of higher amounts of *CDV*, hydroperoxides, and other undesirable compounds formed in RSO during roasting. However, further studies are necessary for application of

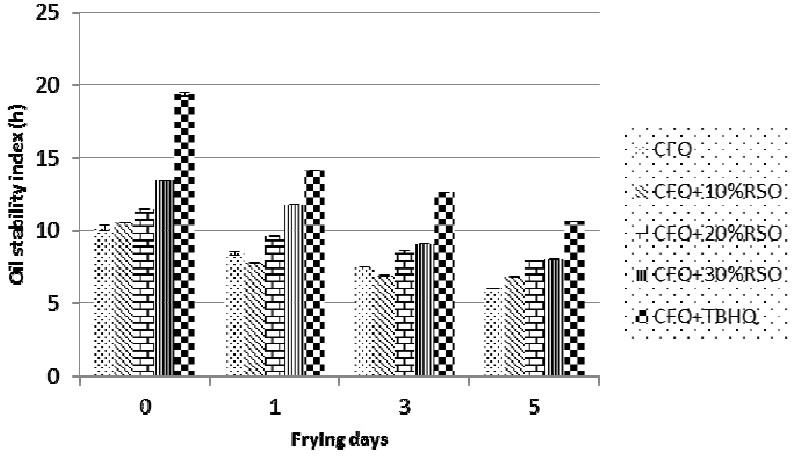

Figure 4. Changes in oxidative stability index (OSI) of frying oils during five consecutive frying days. CFO; CFO+10%RSO; CFO+20%RSO; CFO+30%RSO, and CFO+TBHQ are defined in the text and under Table 2.

Table 4. Fatty acids profile of the frying oils during five consecutive frying days.[a]

Blends	Day	Fatty acids (%) 16:0	18:0	18:1	18:2
CFO [b]	0	22.46±0.04^{aC}	4.36±0.00^{cB}	35.37±0.03^{dA}	35.00±0.00^{cA}
	1	22.59±0.02^{bC}	4.38±0.02^{cB}	35.21±0.01^{dB}	34.91±0.06^{cA}
	3	23.17±0.06^{aB}	4.41±0.02^{cB}	35.17±0.04^{cC}	34.84±0.01^{cAB}
	5	23.61±0.04^{bA}	4.55±0.02^{dA}	35.05±0.07^{dC}	34.34±0.04^{bB}
CFO+10%RSO [c]	0	21.41±0.01^{bC}	4.47±0.02^{bB}	35.60±0.00^{cA}	36.22±0.8^{bA}
	1	21.47±0.03^{cC}	4.50±0.01^{bB}	35.02±0.02^{eB}	35.68±0.03^{bB}
	3	22.21±0.00^{bB}	4.62±0.13^{bA}	34.85±0.04^{dC}	34.71±0.01^{cC}
	5	22.45±0.12^{cA}	4.65±0.04^{cA}	34.81±0.04^{eC}	34.69±0.01^{bC}
CFO+20%RSO [d]	0	20.43±0.08^{cC}	4.57±0.04^{aB}	35.91±0.04^{bA}	36.22±0.01^{bA}
	1	20.48±0.01^{dABC}	4.59±0.04^{aB}	35.55±0.04^{bB}	36.02±0.02^{bA}
	3	20.51±0.01^{cAB}	4.62±0.01^{bB}	35.5±0.08^{bB}	36.06±0.04^{bA}
	5	20.59±0.09^{dA}	4.82±0.03^{bA}	35.44±0.04^{bC}	35.51±0.04^{aB}
CFO+30%RSO [e]	0	19.00±0.07^{dC}	4.58±0.01^{aB}	36.58±0.01^{aA}	37.18±0.03^{aA}
	1	19.08±0.05^{eC}	4.63±0.02^{aB}	36.51±0.01^{aB}	37.11±0.06^{aA}
	3	19.27±0.03^{dB}	4.90±0.02^{aA}	36.28±0.05^{aC}	36.67±0.00^{aB}
	5	20.46±0.02^{cA}	4.93±0.01^{aA}	35.81±0.01^{aD}	35.74±0.04^{aC}
CFO+TBHQ [f]	0	22.51±0.06^{aD}	4.46±0.05^{bB}	35.37±0.00^{dA}	34.39±0.04^{dA}
	1	22.76±0.05^{aC}	4.49±0.01^{bAB}	35.31±0.05^{cB}	34.20±0.04^{dAB}
	3	23.22±0.00^{aB}	4.56±0.05^{bA}	35.20±0.03^{cC}	33.89±0.01^{dBC}
	5	23.77±0.06^{aA}	4.57±0.02^{cdA}	35.14±0.05^{cD}	33.60±0.04^{cC}

[a] A-D: Means within a column with different letters are significantly different (P< 0.05). a-e: Means within a row with different letters are significantly different (P<0.05). [b] Commercial Frying Oil; [c] Commercial Frying Oil+10% roasted sesame oil; [d] Commercial Frying Oil+20% roasted sesame oil; [e] Commercial Frying Oil+30% roasted sesame oil; [f] Commercial Frying Oil+Tert-ButylHydroQuinone,

roasted sesame oil to a frying medium.

REFERENCES

1. Abayeh, O. J., Aina, E. A. and Okounghae, C. O. 1998. Oil Content and Oil Quality Characteristics of Some Nigerian Oils Seeds. *J. Pure Appl. Sci. Tech.,* **1:** 17-23.
2. Abou-ghariba, H., Shehata, A. Y. and Shahidi, F. 2000. Effect of Processing on Oxidative Stability and Lipid Classes of Sesame Oil. *Food Res. Inter*., **33:** 331-340.
3. Akinoso, R., Aboaba, S. A. and Olayanju, T. M. A. 2010. Effects of Moisture Content and Heat Treatment on Peroxide Value and Oxidative Stability of Un-refined Sesame Oil. *Afr. J. Food Agric. Nutr. Dev.,* **10:** 4268-4285.
4. Alireza, S., Tan, C. P., Hamed, M. and Che Man, Y. B. 2010. Effect of Frying Process on Fatty acid Composition and Iodine Value of Selected Vegetable Oils and their Blends. *Inter. Food Res. J*., **17:** 295-302.
5. AOCS. 2004. Official Methods and Recommended Practices of the American Oil Chemists' Society. AOCS Press, Chicago, IL.
6. Awashti, S. K. 2000. Definition of Standards of Quality. In: *"Prevention of Food Adulteration Act with Rules"*, (Ed.): Bhatngar, J. P. 3rd Edition, Ashoka Law House, New Delhi, India, PP. 699-700.
7. Barlow, S. N. 1990. Toxicological Aspects of Antioxidants Used as Food Additives. In: "*Food Antioxidants"*, (Ed.): Hudson, B. J. F.. Elsevier, Amsterdam, PP. 253-307.
8. Basuny, A. M., Arafat, S. M. and Kamel, S. M. 2013. Poly Phenolic Compounds of Eggplant Peel Juice as a Natural Antioxidant for the Stability of Sunflower Oil During Deep Fat Frying. *Curr. Res. Microb. Biotech.,* **1:** 1-8.
9. Borchani, C., Besbes, S., Blecker, Ch. and Attia, H. 2010. Chemical Characteristics and Oxidative Stability of Sesame Seed, Sesame Paste, and Olive Oils. *J. Agr. Sci. Tech.*, **12**: 585-596.
10. Borjian, M., Goli, S.A.H., Gharachourloo, M. and Azizinejad, R. 2015. Optimization of Roasting Process of Sesame Seed to Produce

the High Quality Sesame Oil. *Iran. J. Food Technol. Nutr.,* **12**: 101-111.
11. Capannesi, C., Palche, I., Mascini, M. and Parena, A. 2000. Electrochemical Sensor and Biosensor for Polyphenols Detection in Olive Oils. *J. Agric. Food. Chem*., **71:** 553-562.
12. Cheikh-Rouhou, S., Hentati, B., Besbes, S., Blecker, C., Deroanne, C. and Attia, H. 2006. Chemical Composition and Lipid Fraction Characteristics of Aleppo Pine (*Pinus halepensis* Mill.) Seeds Cultivated in Tunisia. *J. Food Sci. Technol. Int.,* **12:** 407-415.
13. Debnath, S., Rastogi, N. K., Gopala Krishna, A. G. and Lokesh, B. R. 2012. Effect of Frying Cycles on Physical, Chemical and Heat Transfer Quality of Rice Bran Oil during Deep-Fat Frying of Poori: an Indian Traditional Fried Food. *Food Bioproduct. Process*., **90:** 249-256.
14. Farhoosh, R., Tavassoli-Kafrani, M. H. and Sharif, A. 2013. Assaying Antioxidant Characteristics of Sesame Seed, Rice Bran, and Bene Hull Oils and their Unsaponifiable Matters by Using DPPH Radical-Scavenging Model System. *J. Agr. Sci. Tech.,* **15**: 241-253.
15. Fukuda, Y. and Namiki, M. 1988. Recent Studies on Sesame Seed and Oil. *Nippon Shokuhin Kogyo Gakkaishi,* **35:** 552-562.
16. Fukuda, Y., Nagata, M., Osawa, T. and Namiki, M. 1986. Chemical Aspects of the Antioxidative Activity of Roasted Sesame Seed Oil and the Effect of Using the Oil for Frying. *J. Agric. Biol. Chem.,* **50:** 857-862.
17. Hassanein, M. M. M. 2010. Blending of Roasted and Unroasted Sesame Seeds Oils with Sunflower and Olive Oils for Improving Their Antioxidation Potency. *J. Agr. Chem. Biothecnol.,* **1**: 445-456.
18. Hemalatha, S. and Ghafoorunisa. 2007. Sesame Lignans Enhance the Thermal Stability of Edible Vegetable Oil. *Food Chem.,* **105:** 1076-1085.
19. Houhoula, D. P. and Oreopoulou, V. 2004. Predictive Study for the Extent of Deterioration of Potato Chips during Storage. *J. Food Eng.,* **65:** 427-432.
20. Jannat, B., Oveisi, M., Sadeghi, N., Hajimahmoodi, M., Behzadi, M., Choopankari, E. and Behfar, A. 2010. Effect of Roasting Temperature and Time on Healthy Nutraceuticals of Antioxidants and Total Phenolic Content in Iranian Sesame Seeds. *Iran J. Environ. Health Sci. Eng.,* **7:** 97-102.
21. Jaswir, I. Yaakob, B. Che Man and David D. Kitts. 2000. Synergistic Effects of Rosemary, Sage, and Citric Acid on Fatty Acid Retention of Palm Olein during Deep-fat Frying. *J. Am. Oil Chem. Soc.,* **77:** 527-533.
22. Jeong, S. M., Kim, D. R., Kim, S. Y., Nam, K. C., Ahn, D. U. and Lee, S. C. 2004. Effect of Seed Roasting Conditions on the Antioxidant Activity of Defatted Sesame Meal Extracts. *J. Food Sci.,* **69:** 379-381.
23. Kim, H. W. 2000. Studies on the Antioxidant Compounds of Sesame Oil with Roasting Temperature. Korean *J. Food Sci. Technol.,* **32:** 246-251.
24. Koh, S. P., Arifin, N., Tan, C. P., Yusoff, M. S. A., Long, K. and Lai, O. M. 2011. Deep Frying Performance of Enzymatically Synthesized Palm-based Medium- and Long-chain Triacylglycerols Oil Blends. *Food Bioprocess Tech.,* **1:** 124-135.
25. Lalas, S. 2008. Quality of Frying Oil. In: "*Advances in Deep-fat Frying of Foods*", (Eds.): Sahin, S. and Sumnu, S. G.. CRC Press, New York, USA, PP. 57-81.
26. Lee, J., Lee, Y. and Choe, E. 2008. Effects of Sesamol, Sesamin, and Sesamolin Extracted from Roasted Sesame Oil on the Thermal Oxidation of Methyl Linoleate; *LWT - Food Sci. Technol*., **41:** 1871-1875.
27. Lee, S., Jeung, M., Park, M., Lee, S. and Lee, J. 2010. Effect of Roasting Condition of Sesame Seeds on the Oxidative Stability of Pressed Oil during Thermal Oxidation. *Food Chem.,* **118:** 681-685.
28. Lee, Y. C., Kim, I. H., Chang, J., Rhee, Y. K., Oh, H. I. and Park, H. K. 2004. Chemical Compositions and Oxidative Stability of Safflower Oil Prepared with Expeller from Safflower Seeds Roasted at Different Temperatures. *J. Food Sci*., **69**: 33–38.
29. Lin, J. T., Liu, S. C., Hu, C. C., Shyu, Y. S., Hsu, C. Y. and Yang, D. G. 2016. Effects of Roasting Temperature and Duration on Fatty Acid Composition, Phenolic Composition, Maillard Reaction Degree and Antioxidant Attribute of Almond (*Prunus dulcis*) Kernel. *Food Chem.,* **190**: 520–528.
30. Mallikarjunan, P. K., Ngadi, M. O. and Chinnan, M. S. 2010. *Breaded Fried Foods.* CRC Press, New York, NY, PP. 53-76.
31. Manzocco, L., Calligaris, S., Mastrocola, D., Nicoli, M .C. and Lerici, C, R. 2001. Review of Nonenzymatic Browning and Antioxidant Capacity in Processed Foods. *Trends Food Sci. Technol*., **11:** 340–346.
32. Salih AL-Janabi, N. M., Mahmed AL-Samraee, A. M. and Ulaiwi, W. S. 2013. The

Effects of Squeezed Grapes Residue on the Preservation of Stored Fried Potato Chips. *Pak. J. Chem*., **3:** 41-44.
33. Schulte, E. 2004. Economical Micromethod for Determination of Polar Components in Frying Fats. *Eur. J. Lipid Sci. Technol.,* **106:** 772–776.
34. Shahidi, F. 1997. Natural Antioxidants: An Overview. In: "*Naturals Antioxidants: Chemistry and Health Effects and Applications*", (Ed.): Shahidi, F. AOCS Press, Illinois, USA, PP. 1-11.
35. Stier, R. F. 2001. The Measurement of Frying Oil Quality and Authenticity. In: *"Frying Improvement Quality,* (Ed.): Rossel, J. B., CRC Press, New York.
36. Velasco, J., Marmesat, S. and Carmen Dobarganes, M. 2009. Chemistry of Frying. In: "*Advances in Deep-fat Frying of Foods*", (Eds.): Sahin, S. and Sumnu, G. 3th Edition, CRC Press, New York, PP. 33-57.
37. Wu, W. H. 2007. The Contents of Lignans in Commercial Sesame Oils of Taiwan and Their Changes during Heating. *Food Chem*., **104:** 341-344.
38. Yoshida, H. and Takagi, S. 1997. Effect of Roasting Temperature and Time on the Quality Characteristics of Sesame (*Sesame indicum* L.) Oil. *Eur. J. Lipid Sci. Technol*., **75:** 19–26.

اثر روغن کنجد برشته شده بر خواص کیفی روغن سرخ کردنی در طی سرخ کردن عمیق

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چکیده

در این مطالعه ، ابتدا دانه های کنجد برای مدت زمان ۱۹/۳ دقیقه در دمای ۲۱۶/۸°C برشته شدند، سپس روغن آنها استخراج گردید. روغن کنجد برشته شده با نسبت های ۱۰٪، ۲۰٪، ۳۰٪ با روغن سرخ کردنی تجاری مخلوط و در سرخ کردن عمیق برای تهیه چیپس استفاده شد. این فرایند برای ۵ روز متوالی و هر روز به مدت یک ساعت در دمای ۱۸۰ °C انجام شد. کارایی سرخ کردن روغن ها با اندازه گیری پارامترهایی نظیر پراکسید، مقاومت اکسیداتیو، کل ترکیبات قطبی و ترکیب اسیدهای چرب ارزیابی شد. نتایج نشان داد که برشته کردن تاثیر بسزایی بر روی محتوای ترکیبات فنولیک (۲۱ برابر) و مقاومت اکسیداتیو (۳/۶ برابر) روغن کنجد دارد. مقدار کل ترکیبات قطبی به صورت معنی دار در طی سرخ کردن افزایش یافت و به میزان ۲۷٪، ۲۲٪، ۲۱٪، ۲۳/۲٪و ۲۹ درصد به ترتیب برای روغن سرخ کردنی تجاری حاوی ۱۰٪، ۲۰٪ و ۳۰ درصد روغن کنجد برشته شده، روغن سرخ کردنی تجاری حاوی آنتی اکسیدان و روغن سرخ کردنی تجاری به دست آمد. مقاومت اکسیداتیو به صورت معنی دار در طی سرخ کردن کاهش یافت و در روز پنجم روغن سرخ کردنی تجاری حاوی آنتی اکسیدان (۱۰/۶۰ ساعت) و پس از آن روغن سرخ کردنی تجاری حاوی ۳۰٪ روغن کنجد برشته شده بیشترین مقاومت اکسیداتیو را نشان دادند. از طرفی با افزایش میزان روغن کنجد برشته شده، ظرفیت آنتی اکسیدانی روغن های سرخ کردنی افزایش یافت. اگرچه روغن سرخ کردنی تجاری حاوی آنتی اکسیدان فعالیت بیشتری را نسبت به غلظت ۳۰٪ نشان داد.