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ORIGINAL ARTICLE

Enhancing oxidative stability of sunflower oil with sesame (*Sesamum Indicum*) coat ultrasonic extract rich in polyphenols

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Abstract

Addition of antioxidants to oils is essential to retard its oxidation. Nowadays, due to safety concerns, there is a significant demand for replacing synthetic antioxidants with natural ones. Sesame seed coat is a waste product of sesame processing. Ultrasound-assisted extraction of polyphenols from sesame coat was investigated. The highest yield of polyphenols was 7.23 mg gallic acid equivalent (GAE)/g dry nonroasted sesame coat. It was obtained with aqueous ethanol (80%) at a material:solvent ratio of 1:20 (wt/vol) using an ultrasound intensity of 30% of the maximal output power (300 W) for 40 min. High-performance liquid chromatography (HPLC) of the dried extract revealed the presence of sesamin and sesamolin at 65.967 and 38.737 mg/g, respectively. Catechin, *p*-coumaric acid, and chlorogenic acid were the most abundant polyphenols in the extract. The addition of sesame coat extract enhanced the oxidative stability of sunflower oil (423% increase).

Practical applications

Oxidative rancidity is a quality problem of refined vegetable oils. The extraction of polyphenols as a natural source of antioxidants from dried sesame coat using ultrasound was studied. Findings indicate that sesame coat extract improved oxidative stability of sunflower oil. Antioxidant efficacy of the extract was greater than that of synthetic antioxidant BHT.

1 | INTRODUCTION

Sesame (*Sesamum indicum* L.) seeds have been widely consumed for thousands of years. The most common nutritional evaluations of sesame seeds are based on the contents of proteins, oils, and lignans. Sesame seeds are industrially processed as a sesame seed oil, roasted sesame seed, tahini, and tahini halva. The world's production of sesame seeds amounted to about 5 million tons (FAOSTAT, 2017). The sesame coat (testae, bran, and hull) represents about 12% of the sesame seed. It is discarded, or used for animal feed (Elleuch, Bedigian, Besbes, Blecker, & Attia, 2012; Gorguc, Bircan, & Yilmaz, 2019). Sesame coat is rich in polyphenolic compounds, especially lignans. These phenolic compounds have health benefits such as antioxidant, anti-inflammatory, and anticancer activities (Chen & Blumberg, 2008).

Ultrasound has been widely used for extraction of polyphenols from different plant sources. The ultrasound induces cavitation, and mixing phenomena lead to an increase in solid–liquid extraction yield. Bubble explosion in solid/liquid mixtures leads to cell destruction and increases effective surface area for solute extraction (Chemat et al., 2017).

Oil oxidation produces primary products (peroxides, dienes, acids) and secondary products (carbonyls). These products decrease quality characteristics and safety of food. Temperature, light, availability of oxygen, and the presence of metals affect progression of oxidation. Consumers demand high-quality shelf-stable products (Corrigan, Hedderley, & Harvey, 2012). Utilization of synthetic antioxidants is progressively restricted in the food industry because of their potential carcinogenicity. This trend is concomitant with an increasing interest in the utilization of natural antioxidants. However, little work was conducted on the correlations between multicomponent system and antioxidant activity (Zhou, Lin, Abbasi, & Zheng, 2016). Abou-Gharbia, Shahidi, Shahata, and Youssef (1997) found that sesame oil from seeds with coat was more stable than

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that extracted from the dehulled seeds. They attributed this observation to antioxidant components in the sesame coat.

To the best of our knowledge, there are no reports available on the utilization of sesame coat extract as a natural source of antioxidants to extend the oxidative stability of vegetable oils. Therefore, the aims of the present study were to optimize the ultrasound-assisted extraction (UAE) conditions of polyphenols from the sesame coat, identify, and quantify the bioactive compounds of the extract with the highest yield of polyphenols by HPLC and evaluate the antioxidant activity of the extract.

2 | MATERIAL AND METHODS

2.1 | Materials

Sesame seed coat was obtained after dehulling (nonroasted sesame coat) and after roasting (roasted sesame coat) of white sesame seeds from El-Rashidi EL-Mizan Company, Cairo, Egypt. Refined sunflower oil without synthetic antioxidants was obtained from Cairo Oil and Soap Company (Egypt). 2,2-Diphenyl-1-picrylhydrazyl (DPPH), butylated hydroxytoluene (BHT), Folin–Ciocalteu reagent, gallic acid, protocatechuic acid, *p*-hydroxybenzoic acid, chlorogenic acid, caffeic acid, syringic acid, vanillic acid, ferulic acid, sinapic acid, *p*-coumaric acid, rosmarinic acid, cinnamic acid, catechin, rutin, apigenin 7-glucoside, quercetin, apigenin, kaempferol, chrysin, sesamin, sesamolin, and HPLC-grade acetonitrile were purchased from Sigma–Aldrich Co., St. Louis.

2.2 | Extraction of polyphenols

Roasted and nonroasted sesame coat materials were ground into a fine powder and sieved using 20–30-mesh sieve before storing at −20°C. Polyphenolic compounds were extracted from sesame coat powder with aqueous ethanol (80%) using a Fisher Sonic Dismembrator Model 300, USA. Extraction of polyphenols from the nonroasted sesame coat powder was carried out using material/solvent ratios of 1:10 and 1:20 (wt/vol). Meanwhile, extraction from roasted coat powder was performed using a low material/solvent ratio (1:20, wt/vol) since the roasting process affected negatively the polyphenol content as reported by Krol, Gantner, Tatarak, and Hallmann (2020). Extraction was conducted for 10, 20, 30, and 40 min. The ultrasound intensity was used at 10%, 20%, 30% and 40% of the maximum output power (300 W) for 40 min, at ten-minute intervals. The extract with the highest content of polyphenols was concentrated under vacuum at 40°C using EYELA Rotary Evaporator (Tokyo Rikakikai Co., LTD, Japan). The concentrated extract was subjected to further analysis.

2.3 | Determination of total polyphenols

Total polyphenol content was determined in the extracts by the Folin–Ciocalteu reagent using UNICO Spectrophotometer model UV (UNICO Instruments Co., LTD, U.S.A.) at 750 nm according to the Arnous, Makris, and Kefalas (2002) method. The reaction mixture was left in the dark, at room temperature for two hours. Gallic acid was used as a standard. The analysis was performed in triplicate. Results were expressed as mg Gallic acid equivalents (GAE)/g dried material ± standard deviation.

2.4 | Determination of total flavonoids

Total flavonoid content of the concentrated extract was determined by the aluminum chloride colorimetric method using the above-mentioned UV–visible spectrophotometer at 510 nm as described by Formagio et al. (2014). Quercetin was used as a standard. The analysis was performed in triplicate. Values were expressed as mg quercetin equivalents (QE)/g dried material ± standard deviation.

2.5 | High-performance liquid chromatography (HPLC) analyses of phenolic compounds

2.5.1 | Polyphenols

Polyphenol analysis of the concentrated extract was performed according to Kim, Tsao, Yang, and Cui (2006) using Agilent Technologies 1100 series liquid chromatograph (HPLC, Agilent Technologies, USA) equipped with an auto sampler and a diode-array detector. The analytical column was an Eclipse XDB-C_{18} (150 mm × 4.6 µm × 5 µm) with a C_{18} guard column (Phenomenex, Torrance, CA). The mobile phase consisted of acetonitrile (solvent A) and 2% acetic acid in water (vol/vol) (solvent B). The flow rate was kept at 0.8 ml/min for a total run time of 60 min and the gradient program was as follows: 100% B to 85% B in 30 min, 85% B to 50% B in 20 min, 50% B to 0% B in 5 min, and 0% B to 100% B in 5 min. The injection volume was 50 µl and the peaks were monitored simultaneously at 280, 320, and 360 nm for polyphenols and flavonoids. The sample was filtered through a 0.45-µm Acrodisc syringe filter (Gelman Laboratory, MI) before injection. Phenolic compounds were identified by comparing retention time and UV spectra with those of the standards. Quantification was performed with a standard curve of each external standard.

2.5.2 | Sesamin and sesamolin

The concentrated extract was analyzed for sesamin and sesamolin contents according to Wang et al. (2012), using the external standard method by the previous HPLC apparatus with a binary pump and a diode-array and fluorescence detectors. A Hypersil BDS C_{18} reversed-phase column 5 µm, 150 × 4 mm i.d. (Thermo Electron Ltd, UK) was used. The mobile phase was a mixture of acetonitrile–methanol (80/20, v/v) at a flow rate of 0.8 ml/min. Injection volume was 10 µl. Absorption at 280 nm was monitored.

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2.6 | Antioxidant assays

2.6.1 | Scavenging activity of DPPH radicals

Scavenging activity of DPPH radicals was carried out according to Malterud, Farbrot, Huse, and Sund (1993). Two hundred microliters of different concentrations of the extract were added to 2.7 ml of freshly prepared DPPH solution (45 mg/L). The absorbance was measured at 515 nm after an incubation period of 30 min in the dark using UNICO Spectrophotometer model UV (UNICO Instruments Co., LTD, USA). Pure methanol was used as a blank. Butylated hydroxytoluene (BHT) was used as a reference. The percentage of radical inhibition was calculated by the following formula:

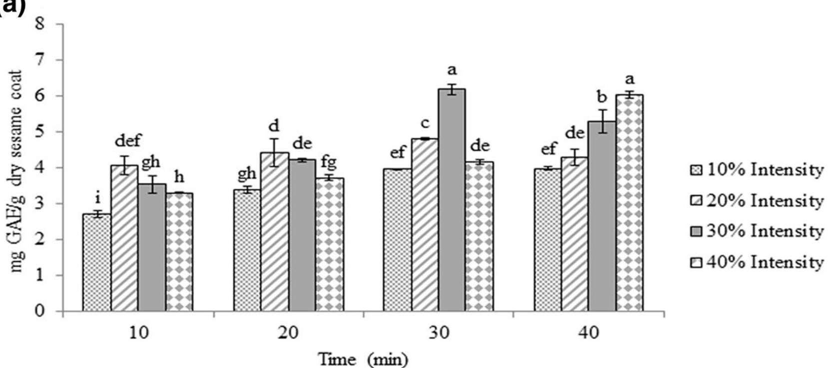
$$\%\,\text{inhibition} = \left[\frac{\text{A0} - \text{A1}}{\text{A0}}\right] \times 100$$

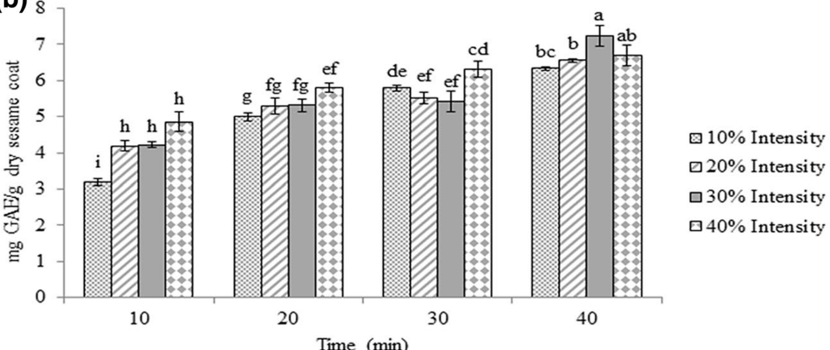
where A0 is the absorbance without sample and A1 is the absorbance with sample.

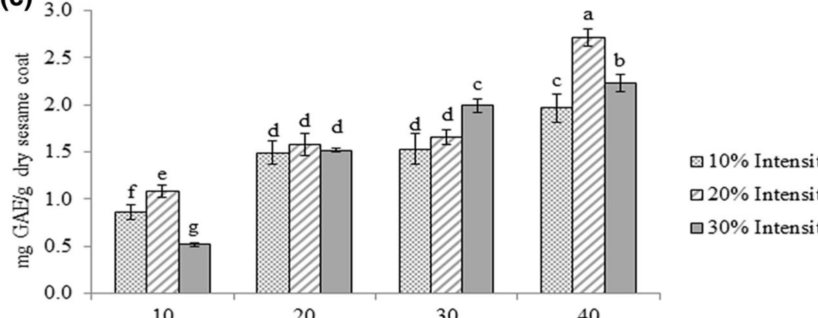
The concentration required for 50% inhibition (IC_{50}) was calculated from the data.

2.6.2 | Reducing power

Antioxidants in extracts reduce ferric chloride and ferricyanide complex to a blue-colored ferrous complex. Higher absorbance of the reaction mixture indicated greater reducing power (Chang, Yen, Huang, & Duh, 2002). Different concentrations of the tested extract in 1 ml of methanol were mixed with phosphate buffer (2.5 ml, 0.2 M, pH 6.6) and potassium ferricyanide [$K_3Fe\,(CN)_6$] (2.5 ml, 1%). The mixture was incubated at 50°C for 20 min. A portion (2.5 ml) of trichloroacetic acid (10%) was added to the mixture, before centrifugation at 1,000 ×*g* for 10 min. The upper layer of the solution (2.5 ml) was collected and







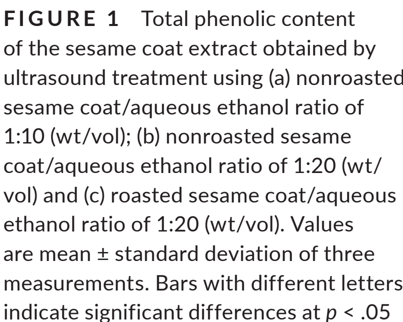


FIGURE 1 Total phenolic content of the sesame coat extract obtained by ultrasound treatment using (a) nonroasted sesame coat/aqueous ethanol ratio of 1:10 (wt/vol); (b) nonroasted sesame coat/aqueous ethanol ratio of 1:20 (wt/vol) and (c) roasted sesame coat/aqueous ethanol ratio of 1:20 (wt/vol). Values are mean ± standard deviation of three measurements. Bars with different letters indicate significant differences at $p < .05$

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FIGURE 2 HPLC profiles of phenolic compounds of sesame coat extract that were simultaneously recorded at 280, 320, and 360

mixed with the same volume of methanol. Ferric chloride (0.5 ml, 0.1%) was added and the absorbance was measured at 700 nm in a spectrophotometer (Milton Roy, Spectronic 1201). Butylated hydroxy toluene (BHT) was used as a reference standard. The IC_{50} value (μg/ml) is the extract concentration at absorbance 0.5 for the reducing power and was calculated from the graph of absorbance at 700 nm against extract concentration.

2.7 | Quality characteristics of oil

Acid value and peroxide value of the refined sunflower oil (free of synthetic antioxidants) were determined according to AOCS (2009) methods. The color of the oil samples was measured using ISO 15305 (1998) method. The measurements were conducted with a Lovibond Tintometer (Tintometer Ltd., Salisbury, UK) using 5.25-inch cell, in triplicate. The yellow filter was fixed at 4 and the intensity of red slides was recorded.

2.8 | Oxidative stability of oil

Evaluation of the oxidative stability of sunflower oil with the investigated extract at concentrations of 200 mg GAE/kg oil at 110°C and 400 mg GAE/kg oil at 120°C in comparison with the synthetic antioxidant (BHT, 200 ppm) at 110°C was carried out by Metrohm Rancimat model 743 (Herisau, Switzerland) according to Pokorny et al. (2003). The induction period (the time elapsed from the beginning until the inflexion point of the conductivity versus time curve) was measured. The air flow rate was 20 L/h. Protection factor (the relative increase in the induction period of oil due to the addition of antioxidant) was calculated according to Turan (2014).

2.9 | Sensory evaluation of sunflower oil samples

Sensory attributes of the sunflower oil (color, aroma, and acceptability) were assessed by 10 panelists. A hedonic scale of 1–9 was used; 9 for excellent and 1 for unacceptable.

2.10 | Statistical analyses

Data were analyzed using a one-way analysis of variance (ANOVA), followed by Tukey's test using XLSTAT version 2014.5. Data are presented as mean ± standard deviation and $p < .05$ was considered statistically significant.

3 | RESULTS AND DISCUSSION

3.1 | Effect of ultrasound-assisted extraction conditions on the yield of polyphenols from sesame coat

Figure 1 shows that increasing sonication time from 10 to 30 min was accompanied by a significant ($p < .05$) increase in the yield of polyphenols obtained by each ultrasound intensity, regardless of nonroasted sesame coat/solvent ratio used.

Extending sonication time from 30 to 40 min at an ultrasound intensity of 10% using 1:10 material/solvent ratio (wt/vol) was not accompanied by a further increase in the yield of polyphenols (Figure 1a). However, the yield of polyphenols decreased significantly ($p < .05$) with the increase in sonication time to 40 min using ultrasound intensities of 20% and 30% (Figure 1a). Increasing

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TABLE 1 Polyphenols of sesame coat extract

Compound	Concentration (mg/g dry extract)
Polyphenols[a]	
p-coumaric acid	41.530
Chlorogenic acid	32.701
Syringic acid	29.635
Vanillic acid	10.975
p-hydroxybenzoic acid	10.389
Protocatechuic acid	10.078
Cinnamic acid	7.759
Ferulic acid	7.226
Rosmarinic acid	3.752
Sinapic acid	2.651
Caffeic acid	0.466
Gallic acid	0.075
Flavonoids[a]	
Catechin	42.852
Apigenin-7-glucoside	9.287
Chrysin	4.582
Apigenin	1.890
Rutin	1.267
Quercetin	0.788
Kaempferol	0.092
Lignans[b]	
Sesamin	65.967
Sesamolin	38.737

[a]Eclipse XDB-C_{18} column.
[b]Hypersil BDS C_{18} reversed-phase column.

ultrasound intensity to 40% of the maximum output power (300 W) and sonication time to 40 min caused a significant increase ($p < .05$) in the total polyphenol yield (Figure 1a). On the other hand, increasing sonication time from 30 to 40 min using a material/solvent ratio of 1:20 (wt/vol) caused a significant increase ($p < .05$) in the yield of polyphenols at each ultrasound intensity used (Figure 1b). Wong Paz, Muniz Marquez, Martinez Avila, Belmares Cerda, and Aguilar (2015) found that the extraction rate of polyphenols decreased sharply after 40 min of extraction.

Decreasing nonroasted sesame coat/solvent ratio (wt/vol) from 1:10 (Figure 1a) to 1:20 (Figure 1b) caused a remarkable increase in the yield of polyphenols at each sonication time, and ultrasound intensity used. A higher solvent-to-material ratio was beneficial for extracting total polyphenols (Chen et al., 2017; He et al., 2016) since it increased the driving force during mass transfer (Vural, Cavuldak, & Anli, 2018).

Increasing ultrasound intensity from 10% to 20% in combination with a material–solvent ratio of 1:10 (wt/vol) and a sonication time of 10, 20, or 30 min caused a significant ($p < .05$) increase in the yield of polyphenols (Figure 1a). A further increase in the ultrasound intensity from 30% to 40% of the maximum ultrasonic output power (300 W) under the same conditions was accompanied by a significant ($p < .05$) decrease in the polyphenol content of the extracts. The same trend could be noticed when the UAE was carried out using a material/solvent ratio of 1:20 (wt/vol), and a sonication time of 40 min (Figure 1b). Altemimi, Choudhry, Watson, and Lightfoot (2015) found that increasing sonication power during UAE of polyphenols from spinach leaves from 30% to 50% of power settings caused a significant increase in the polyphenol yield. However, the polyphenol yield decreased sharply with a further increase in the sonication power to 70% of the power settings.

Roasting of sesame affected negatively the polyphenol yield from the sesame coat. This process decreased significantly ($p < .05$) the yield of total polyphenols from sesame coat to <30% of its original level (nonroasted coat) (Figure 1c). This result is consistent with that reported by Elleuch, Besbes, Blecker, Roiseux, and Attia (2007). They found that roasting of sesame coat decreased the polyphenol content of its methanol extract from 5.98 to 2.6 mg GAE/g. This result is consistent with that found by Gorguc, Ozer, and Yilmaz (2020) who used an ultrasound power of 550 W under vacuum (539 mmHg) for 24 min during extraction. Figure 1c shows that extending sonication time increased significantly ($p < .05$) the yield of polyphenols from roasted sesame coat. Meanwhile, increasing the ultrasound intensity from 10% to 20% of the maximum output power caused a significant ($p < .05$) increase in the yield of polyphenols during the extraction for 40 min. In the present study, the combination of high ultrasound intensity, long sonication time, and low material/solvent ratio enhanced the extraction yield of polyphenols. Results indicated that the highest yield of polyphenols was 7.233 mg GAE/g nonroasted sesame coat. This extract was obtained with ethanol (80%) at a ratio of 1:20 (wt/vol) using an ultrasound intensity of 30% for 40 min. Elleuch et al. (2012) found that the extraction of polyphenols from testae with ethanol 70% by shaking for 2 hr yielded an extract containing 9.29 mg GAE/g dry weight. This difference may be attributed to sesame cultivar and differences in the extraction technique.

With regard to total flavonoid content of the sesame extract with the highest level of polyphenols it was found to be 12.932 ± 0.062 mg QE/g nonroasted sesame coat. Total flavonoid content ranged from 5.80 (black sesame seed) to 8.04 (White sesame seed) g catechin equivalents/kg (Zhou et al., 2016).

3.2 | Phenolic and flavonoid compounds in sesame coat extract

HPLC analysis revealed that the major polyphenols of sesame coat dried extract were *p*-coumaric acid, chlorogenic acid, syringic acid followed by vanillic acid, *p*-hydroxybenzoic acid, and protocatechuic acid. On the other hand, catechin represented the predominant flavonoid in the dried extract as illustrated in Figure 2 and Table 1.

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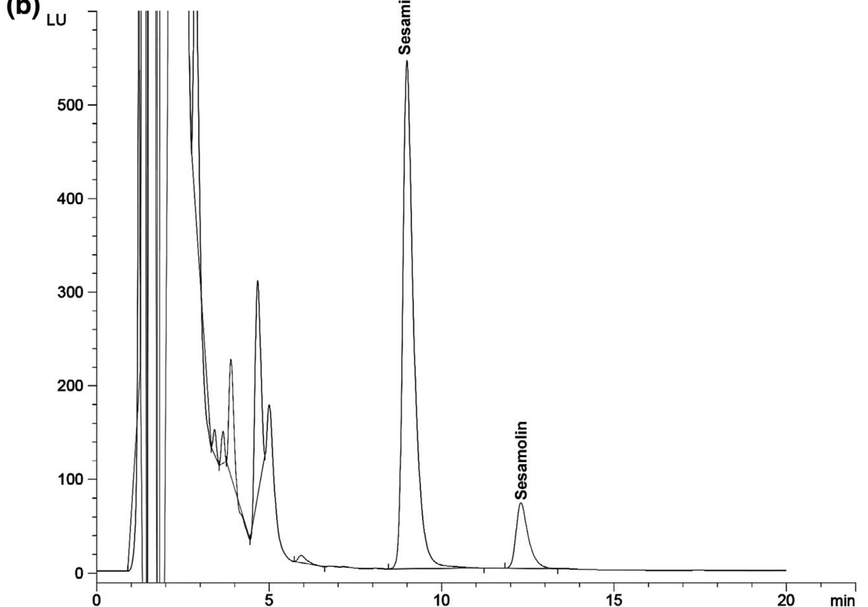

FIGURE 3 HPLC-DAD chromatograms of sesame extract lignans at 280 nm corresponding to (a) standard mixture solution, (b) sesame coat extract

Kermani, Saeidi, Sabzalian, and Gianinetti (2019) reported that seeds of ten sesame genotypes contained different levels of polyphenols. They found that rutin, apigenin, and quercetin contents ranged from not detected to 255.3, 68.4, and 37.2 μg/g dried seed, respectively. Meanwhile, caffeic, *p*-coumaric, and ferulic acids ranged from not detected to 117.6, 92.8, and 69.0 μg/g dried seed, respectively. They also indicated that black sesame seeds contained higher levels of ellagic, ferulic, and caffeic acids as well as apigenin and quercetin compared with white sesame seeds. They reported that white seeds had a *p*-coumaric acid content higher by 4.2-fold than that of black ones while the black seeds exhibited a caffeic acid content by 4.3-fold higher than that of white seeds.

3.3 | Sesamin and sesamolin in sesame coat extract

Sesamin and sesamolin are the main lignans in the sesame seed. Sesamin and sesamolin of the sesame coat extract were screened with HPLC and the results are illustrated in Figure 3 and Table 1.

Sesamin and sesamolin contents were found to be 65.966 and 38.736 mg/g dry extract of sesame coat, respectively. The sesamin-to-sesamolin ratio represented 1.7. Wang et al. (2012) found that this ratio ranged from 1.28 to 1.82 in the sesame seeds. Shi, Liu, Jin, and Wang (2017) examined one hundred sesame seed lines with different coat colors for lignan content. They reported that sesamin content ranged from 1.11 to 9.41 mg/g seed whereas sesamolin content ranged from 0.20 to 3.35 mg/g seed. They

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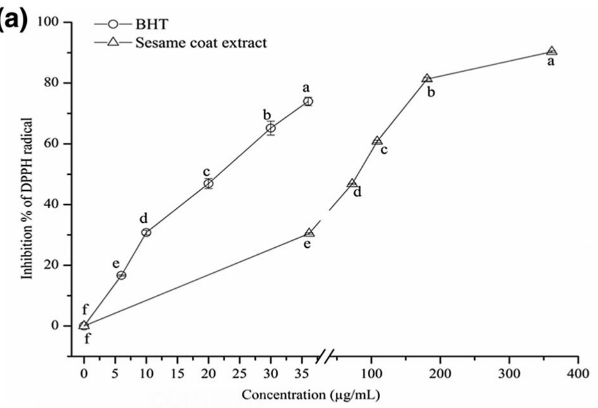

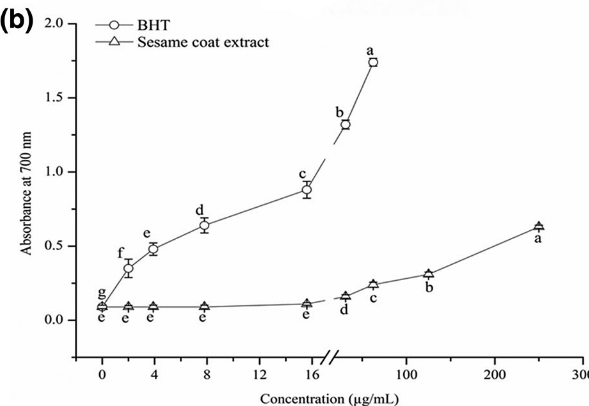

FIGURE 4 Antioxidant properties of sesame coat extract (μg GAE/ml) and BHT (μg/ml) at various concentrations based on (a) inhibition percentage of DPPH radical, and (b) ferric reducing antioxidant power (FRAP value). Results are expressed as mean values of three determinations ± standard deviation. Different lower case letters on bars indicate significance at $p < .05$

found that the highest content of lignans was recorded for the seeds with black coat.

3.4 | Antioxidant activity of sesame coat extract

3.4.1 | DPPH radical scavenging activity

The DPPH radical scavenging activity increased significantly ($p < .05$) with an increase in extract concentration up to 200 μg GAE/ml, after which there was a slower increase in inhibition as illustrated in Figure 4a.

The investigated extract possessed a scavenging activity against DPPH radical of 81.29% at 180.8 μg GAE/ml. The IC_{50} of the extract against DPPH radicals reached 81.01 ± 0.26 μg GAE/ml while it was 21.52 ± 0.6 μg/ml for BHT. Kumar and Singh (2015) reported that sesamin and sesamolin have weak DPPH radical scavenging activity that did not exceed 32% at a concentration of 250 μg/ml.

3.4.2 | Reducing power

The reducing power of the investigated extract is illustrated in Figure 4b. The results indicate that the sesame coat ethanol extract has poor

TABLE 2 Mean values for the oxidation induction time and protection factor of sunflower oil enriched with sesame coat extract measured by the Rancimat at 110°C and 120°C

Sample	Induction time (hr)	Protection factor[c]
Sunflower oil[a]	3.23 ± 0.28	1
Sunflower oil + BHT (200 mg/kg oil)[a]	3.92 ± 0.40	1.21
Sunflower oil + Extract (200 mg GAE/kg oil)[a]	6.23 ± 0.51	1.92
Sunflower oil[b]	1.37 ± 0.11	1
Sunflower oil + Extract (400 mg GAE/kg oil)[b]	7.17 ± 0.88	5.23

Note: The values are expressed as mean ± SD of two independent experiments.
[a]The induction time was determined at 110°C.
[b]The induction time was determined at 120°C.
[c]Induction time of oil containing antioxidant/Induction time of sunflower oil measured at the same temperature.

reducing power compared with BHT. Increasing extract concentration from 2 to 125 μg GAE/ml did not significantly ($p > .05$) cause an increase in the reducing power. The BHT had a higher reducing power than the investigated extract. The highest reducing power of the sesame extract was 0.63 at 250 μg GAE/ml while BHT had the same reducing power at 7.8 μg/ml. Meanwhile, the reducing power of BHT reached 1.76 at 62.5 μg/ml. The IC_{50} values of the sesame coat extract and BHT were 199.22 ± 2.87 and 4.41 ± 0.04 μg/ml, respectively. On the other hand, Chang et al. (2002) reported that 10 mg of sesame coat extract had a reducing power of only 0.35. Sesamin and sesamolin show very low reducing power values compared to BHT (Kumar & Singh, 2015). Turan (2014) found that the highest reducing power in rosemary extract at 2,000 μg/ml was 0.614 while thyme ethanol extract showed a reducing power of 0.24 at 1,000 μg/ml. Rababah et al. (2011) attributed these differences in the antioxidant activity of the plant extracts to the solvents used for extraction and the types of phenolic compounds in these extracts.

3.5 | Oxidative stability of sunflower oil with Rancimat method

The freshness of the investigated sunflower oil was confirmed by its low acid value (0.21 ± 0.01 mg KOH/g) and peroxide value (0.73 ± 0.004 meq/Kg). These quality indices were compatible with the Codex Alimentarius Standards (2019). Induction period and protection factor of sunflower oil containing the sesame coat extract are given in Table 2.

Results demonstrated that all enriched oil samples showed a higher induction time compared to sunflower oil. Results showed that the addition of the sesame coat extract at 200 mg GAE/kg refined sunflower oil (with no added antioxidant) increased oxidative stability of the oil (measured by the Rancimat method at 110°C) by 92% (protection factor 1.92). Meanwhile, the addition of BHT at the same level (200 ppm) to sunflower oil improved its oxidative stability by 21% only. This result is in agreement with that reported by Morsi, Morsy, and Golshany

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TABLE 3 Sensory evaluation of sunflower oil samples

Sample	Color[a]	Aroma	Acceptability
Sunflower oil (control)	8.65[a] ± 0.41	8.95[a] ± 0.16	8.70[a] ± 0.48
Sunflower oil + BHT (200 mg/kg oil)	8.70[a] ± 0.42	8.60[a] ± 0.46	8.75[a] ± 0.35
Sunflower oil + Extract (200 mg GAE/kg oil)	8.80[a] ± 0.26	8.60[a] ± 0.39	8.90[a] ± 0.32
Sunflower oil + Extract (400 mg GAE/kg oil)	8.85[a] ± 0.24	8.50[a] ± 0.47	8.85[a] ± 0.34

[a]The values are expressed as mean ± *SD* ($n = 10$). Means with the same superscript letter in a column are not significantly different (Tukey's test), significance at ($p < .05$).

(2019). The relative stability of oil containing 200 mg GAE from sesame extract/Kg oil represented 1.59× of that required for the same oil supplemented with 200 ppm BHT. This indicated that the shelf life of the treated oil would be 60% more than that for oil supplemented with BHT. As would be expected, the induction time of oil decreased with an increase in temperature from 110°C to 120°C. Increasing temperature by 10°C decreased the induction time by about 50% (Bell, Kaser, Martin, & Scott, 2014). The addition of the investigated extract at 400 mg GAE/kg oil increased its induction time from 1.37 ± 0.11 hr to 7.17 ± 0.88 hr (measured by the Rancimat method at 120°C) (protection factor 5.23). This indicates the high efficiency of the sesame coat extract as a natural source of antioxidants. This result could be attributed to the synergistic activity and combined effect of the polyphenolic active components in the sesame coat extract instead of the activity of each alone.

3.6 | Color

Color is an important quality characteristic of edible oils. The Lovibond red color units of the oil samples containing 200 and 400 mg GAE from sesame coat extract/kg oil or BHT at 200 ppm were 0.4 ± 0.05, 0.5 ± 0.05, and 0.3 ± 0.00, respectively. This result indicated that the color of oil with 400 mg GAE from sesame coat extract/kg was more intense than that of the oil prepared with either 200 mg GAE from sesame coat extract/kg or 200 ppm BHT. According to Codex Alimentarius Commission (2019), there is no upper limit for the color of refined sunflower oil. However, the level of color of the investigated oil samples was lower than that of the commercial sunflower oil sample (2.5 Red + 30 Yellow) as found by Rehab and El Anany (2012). The rise in redness (R) and yellowness (Y) values indicates an increase in the color values of sunflower oil.

3.7 | Sensorial properties of sunflower oil enriched with sesame coat extract

The color and aroma of edible oils are important factors for their acceptability. The sensory evaluation of the sunflower oil samples are summarized in Table 3.

Scores of sensory attributes of oil samples enriched with synthetic antioxidant BHT (200 mg/kg oil) or sesame coat extract at both investigated levels were not significantly different ($p > .05$) from those received by the control oil sample. The sensory properties of the studied oil samples were acceptable (score > 8).

4 | CONCLUSION

The optimal conditions for the ultrasound-assisted extraction of polyphenols from nonroasted sesame coat involved a material:aqueous ethanol ratio of 1:20 (wt/vol) for 40 min using an ultrasound intensity of 30% of the maximum output power (300 W). Roasting sesame seeds decreased sharply the polyphenol content of sesame coat. HPLC analyses of the sesame coat extract indicated the presence of high levels of sesamin and sesamolin besides catechin, *p*-coumaric acid, chlorogenic acid, and syringic acid. The supplementation of sunflower oil with coat extract at 200 and 400 mg GAE/kg oil increased its oxidative stability by 92% and 423%, respectively. This natural extract proved to have no harmful effect on color and sensory properties of oil at both investigated concentrations. The results displayed that the sesame seed coat extract could be used as a promising, inexpensive, and natural source of antioxidants. The valorization of sesame coat minimizes the waste output. Application of this extract would be of great advantage nutritionally and economically.

CONFLICT OF INTEREST

The authors have declared no conflicts of interest for this article.

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