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ORIGINAL ARTICLE

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Optimization of antioxidant extraction process from corn meal using pulsed electric field-subcritical water

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Abstract

In this study, response surface method was used to optimize the extraction of antioxidant extract from corn meal using pulsed electric field (PEF)-subcritical water extraction (SWE) method. Then the extract was used to evaluate its effect on the oxidative stability and fatty acid profile of sesame oil. The corn meal was subjected to different PEF intensities (0.5, 2.5, and 4.5 kV/cm) and then SWE was performed at 110, 130, and 150°C for 30 min. Different properties of the extract including extraction efficiency, phenolic compounds, and 2,2-diphenyl-1-picryl hydrazyl (DPPH) radical scavenging activity and Vitamin C content were measured. The results showed that extraction efficiency, total phenol, and ability to DPPH radical scavenging activity increased at first, but they then decreased by increasing in PEF intensity and subcritical water temperature. In addition, vitamin C content of the extract decreased at higher subcritical water temperature. The optimum processing condition to achieve the highest extraction efficiency and nutritional values was 2.51 kV/cm and 127.91°C. The addition of antioxidants had no effect on changing the profile of fatty acids in sesame oil. The samples containing BHA and 750 ppm of extract showed the same oxidative stability. Finally, PEF-SWE method is introduced as a suitable method for extracting antioxidants.

Novelty impact statement

- Pulsed electric field (PEF)-subcritical water method was used to improve the antioxidants extraction from corn meal.
- The optimum extraction conditions were 2.51 kV/cm and 127.91°C.
- Addition of antioxidants had no effect on changing the profile of fatty acids in sesame oil, and the antioxidant extract improved the oxidative stability of the oil.

1 | INTRODUCTION

Antioxidants are food preservatives to enhance the stability and shelf life of food products from "farm to plate" against the oxidative deterioration. These compounds influence the food acceptance by affecting its texture, color, taste, freshness, aroma, and nutritional values (Griffiths et al., 2016). Different artificial antioxidants such as butylated hydroxytoluene (BHT) and tert-Butylhydroquinone (TBHQ) are usually used in different food formulations. These chemical substances show some toxicities and side effects (Pan et al., 2019; Yang et al., 2017); therefore, it is essential to measure the number of antioxidants in the body tissues and fluids (Franco & Martínez-Pinilla, 2017; Griffiths et al., 2016). These days, the application of natural antioxidants obtaining from different food sources is suggested such as corn germ meal (García-Moreno et al., 2014). It is a by-product of corn industry which includes ground the corn germ and other parts of its kernel (Li et al., 2012). Considering the balance of amino acid composition in germ protein, this by-product can be used to fortify the food products (Kulakova et al., 1982).

There are various extraction methods to recover the polyphenols from plant resources including conventional techniques using hot water or low molecular weight alcohols as a solvent (Ghitescu et al., 2015). Besides, microwave (Bakhshabadi et al., 2017), ultrasound, pulsed electric field (PEF) (Bakhshabadi et al., 2018; García-Pérez et al., 2012; Ghitescu et al., 2015; Moghimi et al., 2018), and subcritical water extraction (SWE) (Kheirkhah et al., 2019; Song et al., 2018) are known as novel methods. These methods are more efficient, faster and need the least amount of solvents in comparison to the conventional procedures (Altemimi et al., 2015).

In PEF treatment, a nonthermal technology, the placed sample between two electrodes, is subjected to short electrical pulses and high voltage. These conditions affect the natural electrostatic charges in the cell membrane. As the potential reaches a critical value, the formation of pores with different sizes will take place resulting in a release of the cytoplasmic fluid and intracellular compounds into the surrounding medium (Grandison & Brennan, 2012). PEF process performance depends on various factors such as pulse number, PEF duration, and cell properties (Mannozzi et al., 2018; Martínez et al., 2019).

Subcritical water is a green extraction solvent with a lower dielectric constant than the organic solvents at higher extraction temperatures (Ju & Howard, 2003; Rodríguez-Meizoso et al., 2006). It can be used as hot water with a temperature between 100°C (water boiling point) and 273°C (water critical point) under adequate high pressure to preserve its liquid form. Subcritical water also is called pressurized hot water, superheated water, high-temperature water, and hot compressed water. It shows different aspects from water at room temperature and supercritical water such as high reactivity and supplementary catalytic activity (Kodama et al., 2016). As the process temperature increases between 100 and 250°C, an increase in hydrolysis reaction will be observed during SWE (Bahari, 2012).

Defining the optimal process condition is essential to increase the effectiveness of bioactive compounds extraction. The response surface method (RSM) is an effective statistical tool used in modeling and optimizing the effects of independent parameters on dependent variables during the food processing. RSM is also helpful in decreasing the number of experimental trials and determining the interaction effects between the variables (Bas & Boyac, 2007; Mansouri et al., 2012; Rostami et al., 2014).

Hence, the aim of this study was to optimize the extraction of the antioxidant compounds from corn meal using the PEF-SWE method and evaluating the effect of these extracts as an antioxidant on the oxidative stability and fatty acid profile of sesame oil.

2 | MATERIALS AND METHODS

2.1 | Materials

The used corn meal was obtained from Khorasan Cotton and Oilseeds Company, Iran. The corn meal was cleaned and stored in resistant plastic bags to prevent air and moisture penetration until the experiments. Folicine Cocaltio, 2 and 6-dichlorophenol indophenol, pure vitamin C, and gallic acid were purchased from Merck Company, Germany. 2,2-diphenyl-1-picryl hydrazyl (DPPH) was provided by Sigma Company. In this study, spectrophotometer (Biochrom, England), laboratory sieve, Rancimat (Metrohm, Switzerland), desiccator, laboratory oven (Memert, Germany), scanning electron microscopy (SEM) (S-360, axford, England), digital scales (Gec Avery, made in England), and gas chromatography (GC) (spectrum, Iran) were used. The PEF and SWE systems were designed in Mashhad Food Industry Institute, Iran.

2.2 | Extraction process

The corn meal (containing 1.00% oil content) was firstly subjected to PEF treatment at different intensities (0.5, 2.5, and 4.5 kV/cm) under constant pulse numbers (30 pulses and with a constant frequency of 1 Hz). After PEF pretreatment, the SWE procedure was performed at 110, 130, and 150°C for 30 min. A subcritical water fluid device equipped with an adjustable pressure pump was used that the pump pressure was set at 30 bar. Also, distilled water was filled in the balance tank of this device with 145 ml capacity. The control sample was prepared using the water extraction process for 18 hr (1:10—samples: water). The obtained extracts were finally dried using a smooth filter and rotary evaporator (Bakhshabadi et al., 2018; Ozel et al., 2003; Shorstkii et al., 2019).

2.3 | The extraction efficiency estimation

In order to determine the extraction efficiency, 10 ml of the extracts (m_1) was carefully weighed. Then, it was dried at 80°C until reaching a constant weight (m_2). Finally, the extraction efficiency was calculated using Equation 1:

$$\text{Extraction efficiency percentage} = \frac{m_2}{m_1} \times 100 \quad (1)$$

2.4 | Determination of total phenolic content

The total phenolic content of the obtained extract was measured according to Shaddel et al. (2014) method. At first, a defined concentration of the sample was mixed with 2.5 ml of Folin-Ciocalteu reagent. Then, it was tenfolds diluted by adding distilled water. About 2 ml of sodium carbonate solution (7.5 g/100 ml) was added to the prepared mixture. It was left at room temperature for 30 min. Finally, the absorbance of the sample was recorded at 765 nm. Different concentrations of Gallic acid (10 to 200 ppm) were prepared and used to prepare the standard graph. Total phenolic content was determined based on Gallic acid equivalent in 100 g of dry sample.

2.5 | Measurement of DPPH free radical scavenging activity

To measure the DPPH free radical scavenging activity, 5 ml of the extract was thoroughly mixed with 1 ml methanol extract. The mixture was incubated for 30 min at room temperature in darkness. The effect of the extract on changes in the DPPH free radicals solution color (from purple to yellow) was recognized at 517 nm (Dolatabadi et al., 2016).

2.6 | Vitamin C content measurement

The spectroscopic method was used to measure vitamin C content in the presence of oxalic acid solution or metaphosphoric acid solution with acetic acid. Based on this method, dye solution 2 and 6-dichlorophenol indophenol were reduced by vitamin C. Additional extraction of the dye solution was done by xylene. The extra amount of dye solution was determined at 500 nm (Rahman et al., 2007).

2.7 | SEM analysis

The micrographic appearances of the PEF-SWE treated sample were studied using SEM (S-360, Axford., England). In order to prevent charging under the electron, the samples were fixed on the silicon wafer and coated with gold (Bakhshabadi et al., 2017).

2.8 | Addition of extracted antioxidant compounds into the sesame oil

At first, the best extracts containing antioxidant compounds were chosen. Then, different levels of these extracts (100, 200, 500, 750, and 1,000 ppm) were added to the refined sesame oil. The prepared samples were then compared with control one (containing no antioxidants) and BHQ and BHA antioxidants at 75 ppm.

2.9 | Evaluating the oxidation stability

A Rancimet device was used to determine the stability of the oil against the oxidation reactions according to the AOCS Cd 12b-92 method (AOCS, 1993). The base of this method is measuring the changes in the electrical conductivity of the water within the device chamber resulting from the produced compounds via the oil oxidation reaction. In this study, 3 g of oil sample was transferred into the Rancimet chamber (110°C). The special cells were filled with 60 ml water having electrical conductivity less than 5 Micro Siemens. The flow rate of inlet air was 20 L/hr. The degree of oxidative stability was estimated by the tangent line on the breaking point of the diagram. The intersection of these tangent lines on the horizontal axis (time) was considered as the degree of stability and resistance of the oil sample per hour.

2.10 | Defining the fatty acids profile

Methylester of fatty acids was firstly prepared to define the structure of fatty acids of the control sample and sample containing the optimal antioxidant extract. Methylester analysis of fatty acids was performed according to the AOCS Ce 2-66method (AOCS, 1993). A GC device equipped with a 70 silica capillary column with a length of 60 m and a diameter of 0.25 μm with a 0.25 μm film thickness was used. The initial temperature (80°C) was increased up to 200°C (15°C/min), and it was kept for 10 min. The temperature was then increased up to 220°C then it was kept at this temperature for 5 min. The injection valve temperature and the detector temperature were 210°C, and the flow rate of carrier gas (helium) was 1 ml/min. Finally, the surface of the obtained curve was compared with the standard curve.

2.11 | Experiment and statistical analysis

Design-expert software (version 6.0.2) was used to optimize the extraction process via the RSM. A central composite rotating design was used to evaluate the effect of independent parameters (electric field intensity (X_1) and subcritical water temperature (X_2)) on dependent variables (extraction efficiency, total phenolic content, DPPH free radical scavenging activity, and vitamin C content). It was important to investigate the interaction of factors and find the best conditions for the extracting process. All coefficients of the quadratic regression model and the interaction effects were therefore estimated.

A completely randomized design was used to evaluate the effect of adding the obtained antioxidant compounds on the oxidative stability and fatty acid profile of sesame oil. Duncan's multiple range tests ($p < .05$) were used to compare the obtained results using SAS software.

3 | RESULTS AND DISCUSSION

3.1 | Effect of processing conditions on extraction yield

As shown in Table 1, the results showed that PEF intensity and SWE temperature had no significant effect on the extraction efficiency of the extract ($p > .05$). However, quadratic parameters and their interaction had a considerable ($p < .05$) impact on this efficiency.

The extraction efficiency increased at first but it then decreased as the PEF intensity and temperature raised (Figure 1). It was found that the SWE temperature has a more considerable effect on changing the extraction yield. The highest extraction efficiency (7.00%) was observed when the PEF intensity and process temperature were 2.5 kV/cm and 130°C, respectively. According to Figure 2, the extraction efficiency improved as a result of creating more holes and ducts in the structure of the optimal sample. The decrease

TABLE 1 Analysis of variance for determined parameters

	Extraction yield			Polyphenol			DPPH scavenging activity			Vit C		
Source	SS	F value	Pb > F	SS	F value	Pb > F	SS	F value	Pb > F	SS	F value	Pb > F
Model	18.10	60.17	<0.0001	7,802.5	17.91	0.0007	1,739.7	34.93	<0.0001	44.86	6.1	0.017
X_1	0.0013	0.02	0.8852	80.9	0.93	0.3672	71.9	7.22	0.031	1.32	0.9	0.37
X_2	0.30	5.0	0.059	5.8	0.066	0.8051	66.3	6.65	0.036	11.65	7.9	0.02
X_1^2	0.75	12.4	0.0096	741.7	8.51	0.022	615.3	61.77	0.001	17.66	12.0	0.01
X_2^2	11.50	191.1	<0.0001	4,466.1	51.26	0.0002	349.9	35.13	0.006	3.30	2.25	0.177
X_1X_2	0.86	14.2	0.007	1.70	0.020	0.8927	58.7	5.90	0.045	0.58	0.4	0.55
Residual	0.42			609.8			69.7			10.30		
Lack of fit	0.39	17.6	0.009	586.9	34.21	0.0026	66.9	31.94	0.003	10.24	262.6	<0.0001
Pure error	0.030			22.8			2.7			0.052		
Cor total	18.52			7,412.4			1,809.5			55.16		

in extraction efficiency could be probably related to the further degradation of the internal grains structure and closure of the outlet ducts as higher PEF intensities were applied (Bakhshabadi et al., 2018; Guderjan et al., 2005; Shorstkii et al., 2020). The required activation energy for the extraction process and adhesion between the plant tissue particles was decreased during processing at higher SWE temperature. High temperatures could also reduce the solvent viscosity and bring its better penetration into the plant tissue resulting in extraction efficiency improvement. However, reduction in the extraction efficiency could be explained as the higher temperature scan causes more wall damages leading to less extraction of the extract from the plant tissue (Giombelli et al., 2020; Ong et al., 2006). Watchararuji et al. (2008) observed an increase in the extraction efficiency of rice bran at higher temperature of subcritical water.

A second-order model was suggested to describe the relation between the extraction efficiency and the treatment processing condition (Table 2). The *F*-value indicates that the quadratic parameter of the subcritical water fluid process temperature has a greater effect on the extraction efficiency (Table 3).

3.2 | The content of phenolic compounds during extraction

The results of Table 2 showed that only the quadratic effects of PEF intensity and process temperature had a significant ($p < .05$) effect on the content of total phenolic compounds. Figure 3 showed an initial increase in the total phenol content at more intense process conditions. However, it decreased at higher PEF intensity and SWE temperature. This increase could be related to the effect of PEF treatment on phenolic compounds release, while the observed decrease showed the destructive effect of the intensive PEF process (Boussetta et al., 2014). These results were in agreement with the reported results by Sarkis et al. (2015) and Bakhshabadi et al. (2018). On the other hand, decomposition of the extracted compounds at higher subcritical fluid temperature was the reason for the increase in the content of phenolic compounds (He et al., 2012). However, softening the texture of the material will take place at the higher temperatures, but the breakdown between phenolic compounds and polysaccharides or proteins reduces the content of phenolic

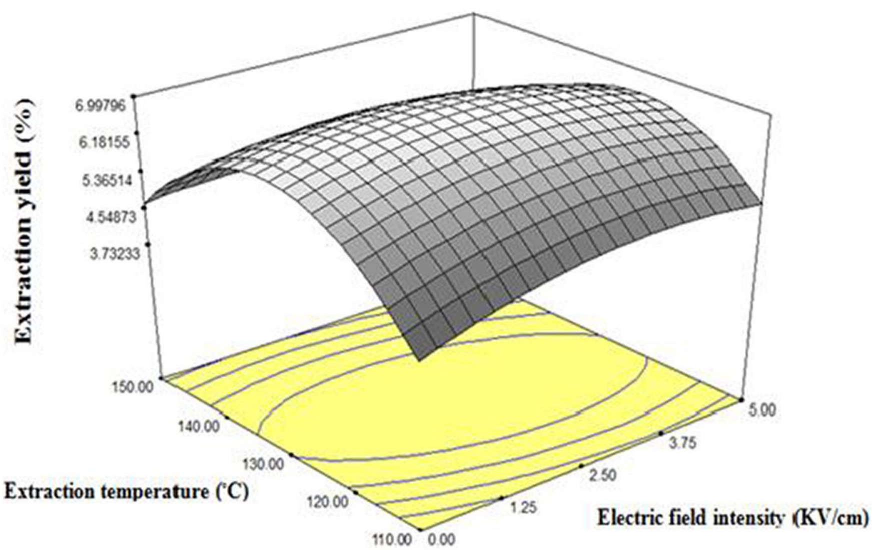

FIGURE 1 The effect of pulsed electric field (PEF) intensity and temperature on the extraction yield

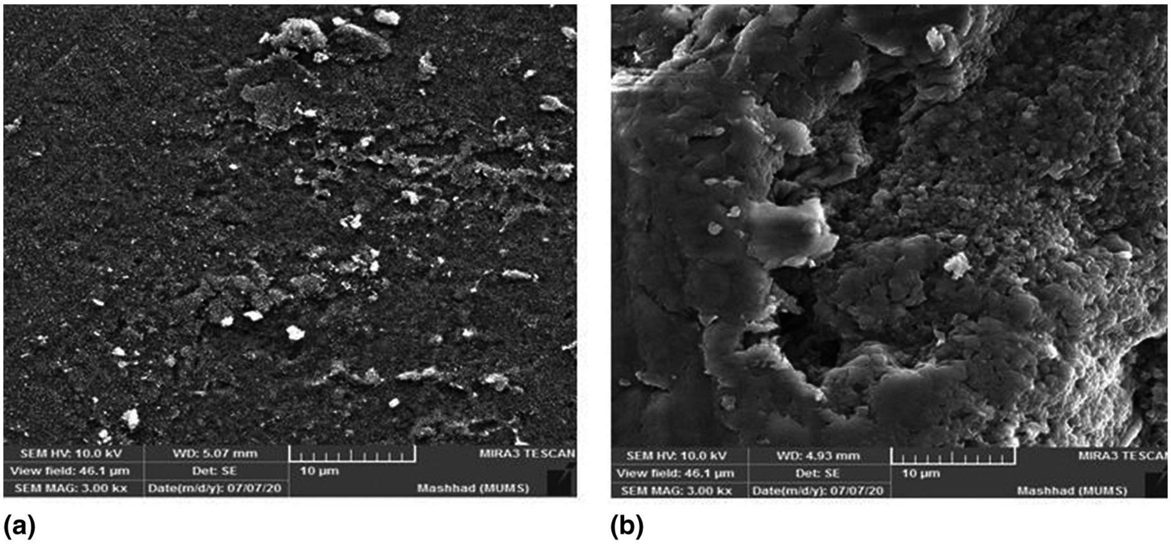

FIGURE 2 Scanning electron microscopy (SEM) graphs of (a) control and (b) the treated sample at the optimum condition during pulsed electric field (PEF) subcritical water treatment

TABLE 2 Model selection for dependent variables (responses)

	Extraction yield		Polyphenol		DPPH scavenging activity		Vit C	
Models	SS	Pb > *F*	SS	Pb > *F*	SS	Pb > *F*	SS	Pb > *F*
Intercept	439.41		415,900		45,457.37		2,624.6	
Linear	0.31	0.9203	86.74	0.9495	138.24	0.6721	12.96	0.2620
Polynomial	0.86	0.522	1.7	0.9667	58.75	0.5809	0.58	0.7319
Quadratic	16.94	<0.0001	7,714.08	0.0001	1,542.78	<0.0001	31.32	0.0075
Cubic	0.36	0.003	140.2	0.5205	11.35	0.6415	9.97	0.0002
Residue	0.041		469.65		58.39		0.33	
Total	457.93		424,300		47,266.88		2,676.76	

TABLE 3 Designed equation models for dependent variable

Number	Dependent variable	Equation	R^2	R^2-adj	CV
1	Extraction yield	$y = +7.00 + 3.46\,X_1 - 0.23\,X_2 - 0.52\,X_1^2 - 2.04\,X_2^2 - 0.46X_1X_2$	.98	.96	4.22
2	Poly phenol	$y = +204.99 - 3.67\,X_1 - 0.98\,X_2 - 16.39\,X_1^2 - 40.21\,X_2^2 + 0.65X_1X_2$	.92	.88	5.22
3	DPPH scavenging activity	$y = +71.22 + 3.46\,X_1 - 3.32\,X_2 - 14.93\,X_1^2 - 11.26\,X_2^2 - 3.83X_1X_2$	.96	.93	5.34
4	Vit C	$y = +15.87 - 0.47\,X_1 - 1.39\,X_2 - 2.53\,X_1^2 - 1.09\,X_2^2 - 0.38X_1X_2$	.81	.68	8.54

compounds (Shi et al., 2003). Also, the possibility of thermal disruption of phenolic compounds at temperatures higher than 130°C could be introduced as the most important factor to decrease the content of these chemicals using SWE (Ahmadian-Kouchaksaraie et al., 2016).

Phenolic compounds are a large group of secondary plant metabolites that their antioxidant capacity is related to the presence of hydroxyl groups in their structure. Attention and application of natural phenols in the food industry are increasing as these prevent the oxidative breakdown of lipids and thus improve the quality and nutritional value of the food (Muanda et al., 2011). It was found that the quadratic of subcritical water temperature had the greatest effect on the content of phenolic compounds of the extracted (Tables 2 and 3).

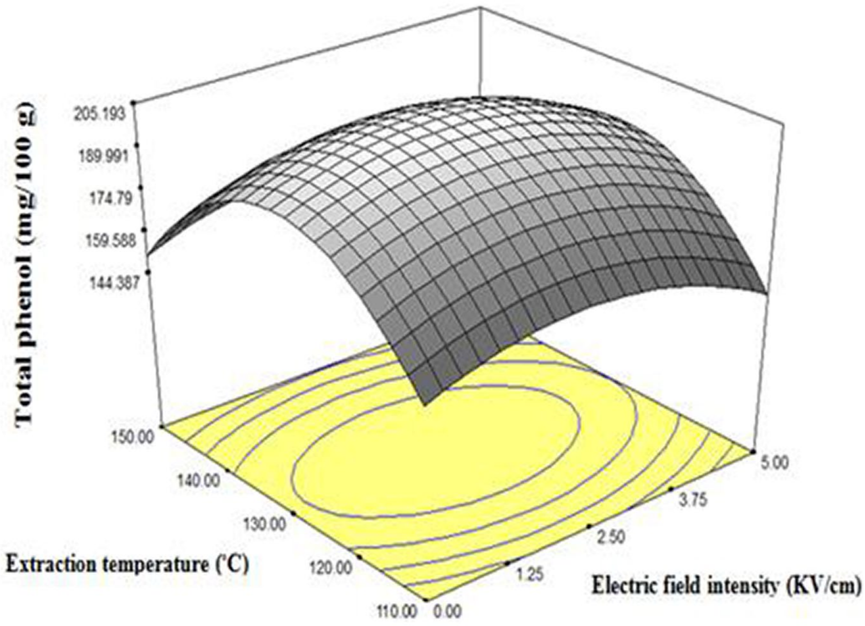

FIGURE 3 The effect of pulsed electric field (PEF) intensity and temperature on total phenolic compounds content

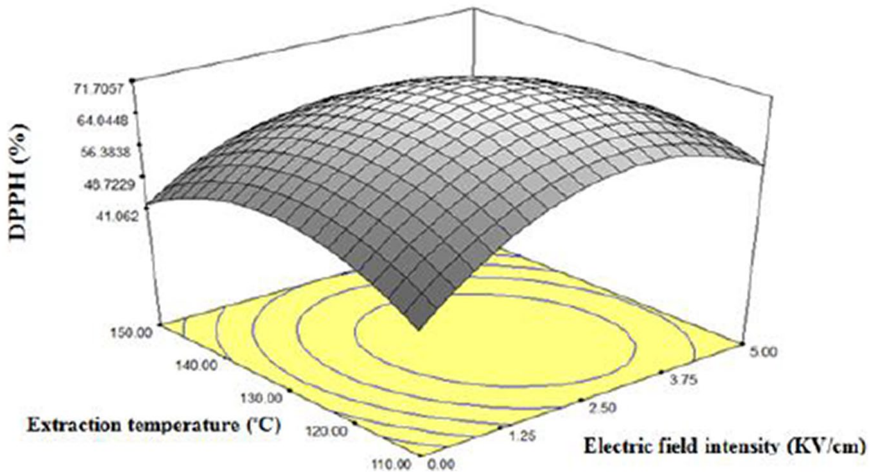

FIGURE 4 The effect of processing conditions on 2,2-diphenyl-1-picryl hydrazyl (DPPH) radical scavenging activity

3.3 | Changes in DPPH radical scavenging activity

DPPH is stable and hydrophilic free radical showing a maximum absorption at 515 to 517 nm due to the presence of single electrons. The transfer of electrons or hydrogen atoms to DPPH radicals from reducing compounds such as phenols and their conversion to a non-radical form causes a decrease in the adsorption of DPPH solution at these wavelengths (Ferreres et al., 2007). DPPH has an amethystine color which its discoloration level indicates the ability to trap or inhibit free radicals by the relevant antioxidant.

In this study, it was found that the independent variable showed a considerable effect ($p < .05$) on DPPH radical scavenging activity (Table 1). During treatment at higher PEF intensity, an initial increase in DPPH activity was observed due to the more release of antioxidants such as tocopherols into the extract. However, the rise in the applied intensities showed the destructive effects causing DPPH activity to decrease (Figure 4). These results were in agreement with Guderjan et al. (2005). The same results were observed during SWE processing at the higher temperatures. Nastić et al. (2018) studied the effect of the water subcritical extraction method on antioxidants of the extract of *mountain germander*. They found higher DPPH radical scavenging activity during processing at the more intense conditions. This finding could be related to the thermal sensitivity of the antioxidants. These results were in agreement with Giombelli et al. (2020) findings. The obtained results in Table 2 revealed that the quadratic model was the best one to describe the effect of extraction process conditions on this chemical property. The suggested model (Table 3) represents that the effect of applied PEF intensity was more considerable than the SWE temperature.

3.4 | Effect of extraction process in the content of Vitamin C

The first-order parameter of process temperature and the second-order parameter of PEF intensity had a significant effect on the

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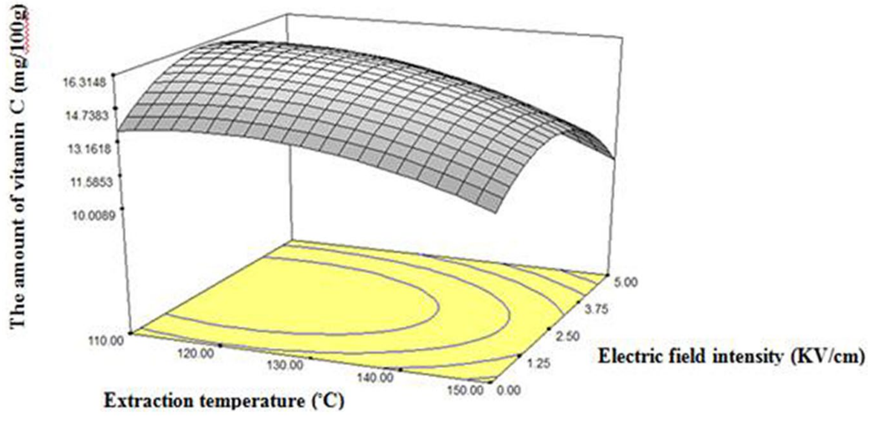

FIGURE 5 The effect of pulsed electric field (PEF) intensity and process temperature on the content of vitamin C

content of vitamin C ($p < .05$) as shown in Table 1. The quadratic model was the best one for fitting the vitamin C results (Table 2) representing the PEF intensity had the key effect on the changes in the content of this vitamin.

Figure 5 showed that the rise in the applied PEF intensity initially caused an increase in vitamin C content due to the more release of this compound into the extract and then showing destructive effect at higher intensities. The results were consistent with the obtained results by Odriozola-Serrano et al. (2013). Zhang et al. (2015) found that the PEF processing at low intensities led to an increase in vitamin C, but an adverse effect was observed during treatment at higher intensities (>15 kV/cm). However, the amount of vitamin C decreased as the temperature of the SWE increased. This fact represents the thermal sensitivity if this vitamin (Figure 5). Jo et al. (2013) observed that the use of subcritical water fluid increases the extraction of vitamin C from oyster mushrooms.

3.5 | Optimization process

The obtained results of optimizing the extraction process showed that the best conditions for achieving the maximum extraction efficiency, total phenol content, DPPH radical scavenging activity, and vitamin C content were 2.51 kV/cm (PEF) and 127.91°C (SWE) (desirability = 0.952).

3.6 | Comparison between the control and produced extract at the optimal condition

Table 4 shows the comparison between the physicochemical properties of the control and the obtained sample at the optimum processing condition. Based on statistical analysis, it can be stated that using PEF-SWE method at the optimal conditions caused an increase in the efficiency and nutritional properties of the extract in comparison to the control ($p < .05$).

3.7 | The effect of antioxidants on the oxidative stability of sesame oil

Different concentrations of the antioxidants (100 to 1,000 ppm), BHA and TBHQ, were used to investigate the effect of antioxidants on the stability of sesame oil (Figure 6). The sample containing TBHQ antioxidant showed the highest oxidative stability following by the samples containing BHA and 750 ppm of the antioxidant extract. However, the control (containing no antioxidants) had the lowest oxidative stability. Increasing the antioxidant level up to 750 ppm led to more oxidative stability concerning the antioxidant properties of these compounds. However, using 1,000 ppm of these extract reduced the stability of the sesame oil due to the pro-oxidant properties of other compounds in plant extracts along with antioxidant compounds having the ability to produce free hydroperoxides. The obtained results were in agreement with Shaker (2006), Khan and Shahidi (2001), and Lee et al. (2004). Natural antioxidants (phenolic compounds such as hydrocinnamicacid, p-courmaric, ferulic, and caffeic acids) in corn meal extract react with the produced free radicals via lipid oxidation to interrupt the chain reactions and increase oxidation stability.

TABLE 4 Comparison between properties of the control and the treated sample at optimum condition

	Type of pretreatment	
Parameter measured	PEF-SWE	Control
Extraction yield (%)	6.99^{a}	3.75^{b}
Total phenol (mg Gallic acid/100 g)	204.36^{a}	139.20^{b}
DPPH (%)	71.45^{a}	43.00^{b}
Vitamin C (mg/100 g)	16.00^{a}	8.51^{b}

Note: Mean ± *SD* of treatments with the same letters are not significantly different at any time ($p > .05$).

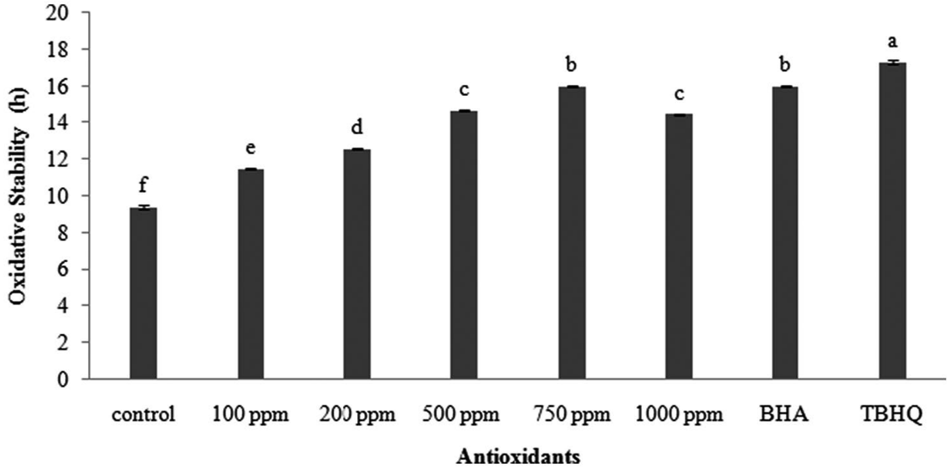

FIGURE 6 The effect of antioxidant type on the stability of sesame oil

TABLE 5 The effect of antioxidant addition on the fatty acid profile of sesame oil

Fatty acids	Structure	The amount of fatty acids: Control	The amount of fatty acids: Contains antioxidants
Palmitic acid	C16:0	8.65 ± 0.05^c	8.65 ± 0.02^c
Palmitoleic acid	C16:1	0.12 ± 0.00^h	0.12 ± 0.01^h
Stearic acid	C18:0	4.70 ± 0.03^d	4.69 ± 0.03^d
Oleic acid	C18:1	40.70 ± 0.23^b	40.70 ± 0.23^b
Linoleic acid	C18:2	44.47 ± 0.36^a	44.48 ± 0.36^a
Linolenic acid	C18:3	0.64 ± 0.01^e	0.64 ± 0.01^e
Arachidic acid	C20:0	0.42 ± 0.03^f	0.42 ± 0.03^f
Eicosenoic acid	C20:1	0.30 ± 0.00^g	0.30 ± 0.00^g

Note:: Numbers with different letters in each column imply significant differences in the 5% level of probability.

3.8 | The effect of antioxidant extract on the fatty acid profile

It was found that linoleic acid was the predominant fatty acid in the sesame oil. This oil is principally consisted of triglycerides followed by diglycerides, free fatty acids, polar lipids, and finally monoglycerides. It also contains considerable levels of phytosterols, tocopherols, and Lignans (mainly sesamin and sesamolin) (Reshma et al., 2010). As Table 5 shows, the use of antioxidants had no significant ($p > .05$) effect on the fatty acids in sesame oil. In general, this oil showed a good oxidative stability even if 85% of fatty acid contents in this seed are unsaturated (Abou-Gharbia et al., 2000; Shahidi et al., 1997).

4 | CONCLUSION

The results of this study showed that the use of the PEF-SWE method led to an increase in the antioxidant activity and vitamin C content of the corn meal extract. The results of optimizing the process condition showed extraction at 2.51 kV/cm and 127.91°C resulted in highest extraction efficiency and nutritional values. On the other hand, the use of extracted antioxidants up 750 ppm in sesame oil increased the oxidative stability of the oil and the use of these antioxidants did not affect the fatty acid profile of the oil.

CONFLICT OF INTEREST

The authors have declared no conflicts of interest for this article

AUTHOR CONTRIBUTIONS

Seid Mehdi Hosseini: Project administration. **Abolfazl Bojmehrani:** Data curation; Formal analysis; Writing-original draft. **Ehsan Zare:** Project administration; Software. **Zahra Zare:** Investigation; Methodology. **Seid Mohammad Hosseini:** Funding acquisition; Visualization. **Hamid Bakhshabadi:** Data curation; Formal analysis; Funding acquisition; Methodology; Software.

DATA AVAILABILITY STATEMENT

Data available on request from the authors: The data that support the findings of this study are available from the corresponding author upon reasonable request.

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