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Research Article

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Effect of Optimizing the Black Plum Peel Extract as Natural Antioxidant and Storage Time on Oxidative Stability of Sunflower Oil

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Abstract

Today, the use of natural antioxidants is attracting the attention of consumers. Black plum peel is the waste of plum processing and is the source of antioxidants. In this research, the effect of black plum peel extract (BPPE) (0, 400, and 800 ppm) as a natural antioxidant and storage time (0, 8, and 16 days) on the oxidative stability parameters (peroxide value, free fatty acids, thiobarbituric acid, conjugated dienes, and carbonyl value) of sunflower oil with response surface methodology (RSM) method was studied. The predominant polyunsaturated and monounsaturated fatty acid (MUFA) in sunflower oil were C18:2C (63.77%) and C18:1C (24.86%), respectively. Increasing the storage time up to 8 days caused to increase the peroxide value and thiobarbituric acid and there were reduced from 8 to 16 days ($p < 0.05$). Increasing the storage time increased the conjugated dienes sharply, however it was reduced very slow by increasing the BPPE ($p < 0.05$). Free fatty acid content and carbonyl value of the oil increased non-linearly by the storage time ($p < 0.05$). The best conditions for sunflower oil were 3 days and 472.73 ppm black plum peel concentration ($R^2 = 0.71$). The RSM was usable for determining the optimal concentration of BPPE for oxidative stability of sunflower oil.

Kewords

Sunflower oil, Black plum peel, Natural antioxidant, Optimization

Introduction

Sunflower oil occupies a prominent position among edible oils due to its exceptional quality. It is highly regarded for its numerous beneficial properties and versatile applications in culinary, food technology and pharmaceuticals. It is also considered a valuable source of essential fatty acids and linoleic acid [1-3]. However, a higher content of unsaturated and polyunsaturated fatty acids can lead to oxidation, resulting in an abysmal taste and odor [1]. Moreover, oxidation can have a significant impact on the color and quality of food [1, 4]. Autoxidation can occur in the presence of various factors such as heat, light, and transition metals [1]. The process initiates and continues through a free radical chain and can ultimately form free radicals, peroxide free radicals, and hydroperoxides. There are several ways to inhibit lipid oxidation include deactivating enzymes that promote oxidation, incorporating chelating agents, employing appropriate packaging techniques, and adding antioxidants. However, despite low cost and high stability of synthetic antioxidants in food technology, the increased awareness of consumers about their synthetic compounds carcinogenic [2, 5-9]. Natural antioxidants are especially effective and preferable, as long-term use of synthetic antioxidants has raised concerns about potential toxicity due to the phenolic compounds [5, 6].

The *Prunus domestica* L., commonly referred to as the plum tree, is a deciduous member of the Rosaceae family [10, 11]. Plums are considered one of the most important agricultural products in Iran, holding significant importance as a fruit [12]. They are known for their wide range of flavors and textures, which can be attributed to the diverse varieties that are cultivated [11]. They are also characterized by their low-calorie content and high nutritional value. Plums are indeed abundant in diverse carbohydrates, including sucrose, glucose, fructose, and sorbitol. Moreover, they possess organic acids like citric acid and malic acid, soluble fiber in the form of pectin, tannins, volatile substances, and enzymes [11]. These compounds contribute to the unique taste, nutritional value, and health benefits of plums. From a nutritional standpoint, plums are a rich source of minerals such as iron, calcium, phosphorus, manganese, sulfur, magnesium, and potassium, along with vitamins A, B, C, and PP. Plums also contain substantial amounts of dietary fiber, sorbitol, anthocyanins, carotenoids, and phenolics [11]. In the process of plum fruit processing, particularly during drying, the plum peel is often left as a by-product. This residual material has a high moisture content and is prone to microbial spoilage. Unfortunately, it is frequently discarded into the environment, leading to environmental pollution. The black plum peel puree has been found to contain a high concentration of antioxidants, with a reported value of 88.59%. Furthermore, the total phenolic compounds in the puree are measured at 105.91 mg/g GA (gallic acid equivalent). These findings indicate the remarkable antioxidant and phenolic content present in the black plum peel puree, indicating its potential health benefits [11].

Extensive research has been conducted on the utilization of fruit and vegetable extracts as natural antioxidants to enhance the stability of edible oils, as indicated by the literature review [1, 2, 5, 7, 8, 10, 13-15]. Therefore, the objective of this study was to specifically examine the impact of BPPE at various concentrations (0, 400, and 800 ppm) as a natural antioxidant. The study aimed to assess how this extract influenced oxidative stability parameters, including peroxide value, free fatty acids, thiobarbituric acid, conjugated dienes, and carbonyl value, during the storage period. The storage conditions involved subjecting the oil to a temperature of 60 °C for 0, 8 and 16 days.

Materials and Methods

Preparation of BPPE

The plum peel underwent a thorough washing process to eliminate impurities. Subsequently, it was crushed using an industrial crusher before being stored in a freezer for the upcoming experiments. To create the black plum peel extract, approximately 10 g of BPPE was dissolved in 100 ml of 80% ethanol and heated at 50 °C for a duration of 18 to 24 h. The resulting mixture was then filtered using Whatman filter paper 1 and a Buchner funnel. The solvent was subsequently evaporated, and the resulting BPPE was then stored at a temperature of -18 °C until the experiments commenced.

Preparation of oil sample

Refined sunflower oil was sourced from the Shadgol industry in Neyshabur, Iran. To assess its antioxidant properties, BPPE was incorporated into sunflower oil at different concentrations (0, 400, and 800 ppm). The samples were then subjected to storage at 60 °C, a selective temperature. Throughout this period, various quality characteristics of the sunflower oil, including peroxide value, free fatty acids, thiobarbituric acid, conjugated dienes, and carbonyl value, were measured at intervals of 0, 8, and 16 days.

Fatty acid composition

In this study, the chemical composition of sunflower oil was examined using the GC/MS technique. The analyses were conducted on a Shimadzu GCMS-QP2010 ultra mass spectrometer, which was equipped with a flame ionic detector and coupled with a GC2010 gas chromatograph. To separate the components of interest, an InertCap5 capillary column measuring 60.0 m × 0.25 mm × 0.25 µm was employed. Helium was chosen as the carrier gas, with a split ratio of 1:5 and a linear velocity of 35.2 cm/s. The oven temperature was programmed to create a gradient: starting at 60 °C, it was maintained for 4 min, then increased to 280 °C at a rate of 4 °C/min, and finally held at 280 °C for 10 min. The injector temperature was set to 250 °C, while the detector temperature was set at 300 °C. The ion source temperature for the mass spectrometer was maintained at 200 °C. In summary, the GC/MS analysis of sunflower oil was carried out using a Shimadzu GCMS-QP2010 ultra mass spectrometer with specific settings for the column, carrier gas, temperature gradient, injector, detector, and ion source [10].

Free fatty acids determination

The analysis of free fatty acids involved the use of a 2 mg sample that had been neutralized by treating it with a mixture of 50 ml petroleum ether and ethanol in a 1:1 ratio [10]. The neutralized sample was manually shaken and allowed to cool to room temperature.

Next, the solution was titrated with 0.1 m potassium hydroxide (KOH), and an indicator called phenolphthalein solution was used. The free fatty acids values were determined using equation 1:

$$\text{Free fatty acids } (ml/g) = \frac{(V \times C \times 56.11)}{m}$$

Where: V represents the volume of KOH used, C denotes the concentration of KOH, and m represents the weight of the oil sample. By plugging in the appropriate values, the free fatty acids content of the sample could be calculated.

Peroxide value determination

The peroxide value of the oil samples was determined following the method described by Drinić et al. [7] in 2020. Initially, 0.2 mg of each oil was combined with chloroform and ethanol. Subsequently, 50 µl of iron (II) chloride solution and 50 µl of 30% (w/v) ammonium thiocyanate solution were added to the mixture, which was then vigorously shaken for a duration of 2 - 4 seconds. After allowing the samples to incubate at room temperature, the absorbance was measured at 500 nm. The results were reported in milliequivalents of oxygen per kg of each sample.

Thiobarbituric acid value determination

The analysis of thiobarbituric acid was conducted following the method described by Drinić et al. [7] in 2020. For each sample, 200 mg was dissolved in 25 ml of 1-butanol. After thorough mixing, 10 ml of 2% thiobarbituric acid solution was added to 5 ml of this mixture, and the resulting solution was incubated at 95 °C for 2 h. Subsequently, the mixture was cooled in a water bath until reaching 25 °C. The absorbance was then measured at 532 nm. Thiobarbituric acid values were determined using equation 2:

$$\text{Thiobarbituric acid} = \frac{5(A-B)}{M}$$

Where: A represents the absorbance, B is the absorbance of the control sample, and m represents the mass of the oil sample.

Conjugated diene determination

The analysis of conjugated dienes was carried out following the method outlined by Delfanian et al. [14] in 2016. Around 5 mg of oil samples were dissolved in 10 ml of cyclohexane. The absorbance of the solution was then measured at 233 nm.

Carbonyl value determination

The determination of the carbonyl value followed the method described by Delfanian et al. [14] in 2016. A calibration curve of standard aldehyde (2, 4-Decadienal) was plotted within a concentration range of 50 - 500 µM. A mixture of 50 mg of 2,4 D-nitrophenyl hydrazine (DNH) and 100 ml of 2-propanol was prepared. Approximately 0.15 g of the oil sample was placed in a volumetric flask and filled with a solvent containing 0.4 mg/ml of triphenylphosphine (TPP). Next, 1 ml of the DNH solution was added to 1 ml of the prepared sample solution and allowed to incubate at 40 °C for 20 min. The solution was then cooled, and 8 ml of 2% KOH was added before centrifuging for 5 min at 2000 rpm. The absorbance of the supernatant was measured at 420 nm, and the obtained results were reported in micromoles of 2, 4-Decadienal per gram of each sample.

Statistical analysis

RSM was used to study the effect BPPE (0, 400, and 800 ppm) as a natural antioxidant and storage time (0, 8, and 16 days) on the oxidative stability parameters (peroxide value, free fatty acids, thiobarbituric acid, conjugated dienes, and carbonyl value) of sunflower oil using a central composite rotatable design. Four models contained linear, 2FI, quadratic and cubic were used to fit data. Statistical analysis performed by Design Expert software, 13 editions. Experiments were performed in 3 replications (Table 1).

Table 1: Fatty acid composition of sunflower oil.

Name	Percentage (%)
C14:0	0.05
C16:0	6.56
C16:1	0.08
C18:0	3.2
C18:1T	0.01
C18:1C	24.86
C18:2T	0.05
C18:2C	63.77
C20:0	0.22
C18:3	0.10
C20:1	0.15
C22:0	0.67
C24:0	0.24

Results and Discussion

Fatty acid composition

Table 2 presents the fatty acid composition of sunflower oil. Evidently, the polyunsaturated (ω_6) fatty acid (PUFA), specifically C18:2C, exhibits a considerably higher proportion. Furthermore, the second most abundant fatty acid is MUFA, with oleic acid being the predominant component. These findings align with the results obtained in the studies conducted by Kozlowska and Gruczyńska et al. [2] and Elsayed et al. [10] regarding the fatty acid composition.

Peroxide value

Oxidation of fatty products causes peroxides that have harmful effect on food quality and human health. Totally, the higher the amount of unsaturated fatty acids, the more ready for oxidation. By increasing the oxidation process, aldehydes, ketones, and volatile compounds are produced, which can cause unpleasant taste and flavor. So, to determine the peroxide value is a good method to predict the organoleptic properties of oil. One of the important factors that can increase the oxidation process is temperature and storage time. Table 2 shows that the best model for fitting the peroxide value was the quadratic model (p = 0.0043). It can also be seen in table 3, the linear and square parameters of storage time on the peroxide value of sunflower oil was significant (p < 0.01), although

Table 2: Model selection for dependent variables.

Variable/Model	Linear		2FI		Quadratic		Cubic		Residual	Total
	Sum of squares	P - value	Sum of squares	P - value	Sum of squares	P - value	Sum of squares	P - value	Sum of squares	Sum of squares
Peroxide value (meq/kg)	7.16	0.0306	0.0124	0.9001	4.56	0.0043	0.3393	0.2672	0.2405	44.48
Free fatty acid content (mg/g)	6.39	0.0006	0.0049	0.8702	1.17	< 0.0001	0.0062	0.6012	0.0153	15.03
Thiobarbitoric acid (mg/kg)	8.33×10^{-6}	0.9814	0.000	0.6693	0.0016	0.0007	0.0001	0.0328	9.78×10^{-6}	0.0196
Conjugated dienes (mMol/L)	0.0033	< 0.0001	3.61×10^{-6}	0.1810	2.55×10^{-6}	0.5081	3.23×10^{-6}	0.5081	5.668×10^{-6}	0.0158
Carbonyl value (mMol/g)	1.120	< 0.0001	0.0003	0.8789	0.0743	0.0001	0.0017	0.0766	0.0004	13.71

Table 3: Analysis of variance for determined parameters.

Variable		Model	X_1^*	X_2^{**}	X_1X_2	X_1^2	X_2^2	Residual	Pure error	Cor total
Peroxide value (meq/kg)	Sum of squares	11.73	7.08	0.0741	0.0124	3.72	0.1349	0.5759	0.0013	12.31
	P - value	0.0025	0.0005	0.4602	0.7566	0.0024	0.3300	-	-	-
Free fatty acid content (mg/g)	Sum of squares	7.56	6.37	0.0178	0.0049	1.12	0.0037	0.0215	4.667×10^{-6}	7.59
	P - value	< 0.0001	< 0.0001	0.0976	0.3349	< 0.0001	0.3898	-	-	-
Thiobarbituric acid (mg/kg)	Sum of squares	0.0017	4.167×10^{-6}	4.167×10^{-6}	0.000	0.0015	3.244×10^{-6}	0.0001	8.667×10^{-6}	0.0018
	P - value	0.0034	0.6600	0.6600	0.1700	0.0003	0.6973	-	-	-
Conjugated dienes (mMol/L)	Sum of squares	0.0033	0.0032	0.000	-	-	-	0.00	4.667×10^{-6}	0.0033
	P - value	< 0.0001	< 0.0001	0.0489	-	-	-	-	-	-
Carbonyl value (m Mol/g)	Sum of squares	1.20	1.12	0.000	0.0003	0.0734	0.0019	0.0021	2×10^{-6}	1.2
	P - value	< 0.0001	< 0.0001	0.790	0.4542	< 0.0001	0.0821	-	-	-

Note: X_1^*: Storage time; and X_2^{**}: Black plum peel extract.

the effect of BPPE and interaction of storage time and BPPE were not significant ($p > 0.05$). In the other hand, the result indicates that BPPE was beneficial in controlling the peroxide value as an antioxidant. As the storage time increased up to 8 days, the peroxide value of the oil increased, but with increase from 8 to 16 days, the peroxide value reduced (Figure 1). Probably, from the 8th day onwards, BPPE has been able to show its antioxidant role and reduced oxidation process. According to the results of table 4, the square parameter of the storage time had the greatest effect on the peroxide value of sunflower seed oil. Figure 2 shows the effect of storage time on the stability parameters of commercial sunflower seed oil. It seems that increasing the storage time up to 16 days peroxide value increased ($p < 0.05$). According to the results, the addition of BPPE has prevented the increase of peroxide value, so it can be said the usage of BPPE as a natural antioxidant caused desirable quality in the edible oil. In this study, the peroxide value of sunflower oil was 0.045 - 2.65 meq/kg. Romeo et al. [16] extracted the phenolic compounds of olive wastewater and used them as natural antioxidants in sunflower oil. Storage time was 0 - 90 days and temperature was 10 and 25 °C. Peroxide value was 2.95 - 5.51 m Eq O_2 kg^{-1}. Their results showed that oxidative stability of sunflower oil contained olive wastewater extract was 50% more than control sample. More et al. [17] extracted the bioactive compounds of moringa leaves and pomegranate peel and used as natural antioxidants in the edible oil contained medium chain triacylglycerols. They reported that natural extracts could reduce the oxidation rate

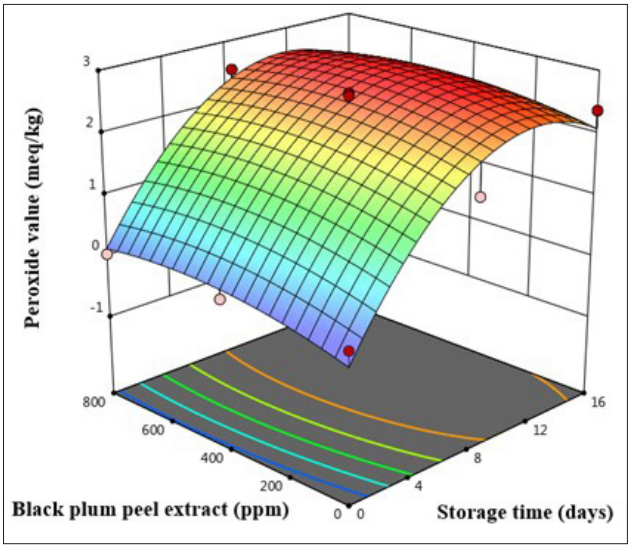

Figure 1: The effect of black plum peel extract and storage time on the peroxide value of sunflower seed oil.

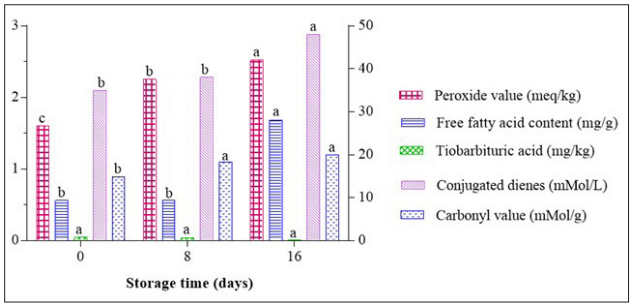

Figure 2: The effect of storage time on the stability parameters of commercial sunflower seed oil.

Table 4: Designed equation models for dependent variables.

Dependent variable	Equation	R^2	R^2 - adjusted	CV (%)	Predicted data	Real data
Peroxide value (meq/kg)	$Y = +2.5 + 1.09\,X_1 + 0.1112\,X_2 - 0.0558\,X_1X_2 - 1.21\,X_1^2 - 0.2308\,X_2^2$	0.9529	0.9058	19.91	1.364	1.47
Free fatty acid content (mg/g)	$Y = +0.4815 + 1.03\,X_1 - 0.0545\,X_2 - 0.035\,X_1X_2 + 0.6647\,X_1^2 - 0.0388\,X_2^2$	0.9972	0.9943	7.98	0.089	0.081
Thiobarbituric acid (mg/kg)	$Y = +0.0541 - 0.0008\,X_1 + 0.0008\,X_2 + 0.035\,X_1X_2 - 0.0241\,X_1^2 - 0.0011X_2^2$	0.9465	0.8930	10.85	0.045	0.049
Conjugated dienes (mMol/L)	$Y = +0.03237 - 0.0233\,X_1 - 0.0013X_2$	0.9954	0.9942	4.07	0.019	0.210
Carbonyl value (mMol/g)	$Y = +1.14 + 0.4323X_1 - 0.0023\,X_2 + 0.0083\,X_1X_2 - 0.1703\,X1^2 + 0.0477X2^2$	0.9983	0.9965	1.91	0.807	0.76

Note: X_1: Storage time; and X_2: Black plum peel extract.

at ambient and higher temperatures. Mohdaly et al. [18] studied antioxidant activity of sesame cake extract on sunflower and soybean oils and compared with synthetic antioxidants. Samples were examined at 70 °C and up to 72 h. Antioxidant activity of sesame cake extract was higher than BHA and BHT and lower than TBHQ.

Free fatty acid content

Hydrolysis of triglycerides produce free fatty acids, which play an important role in the rancidity of oils. Table 2 shows that the best model for fitting the free fatty acid content was the quadratic model ($p < 0.0001$). It can also be seen in table 3, the linear and square parameters of storage time on the free fatty acid content of sunflower oil was significant ($p < 0.0001$), although the effect of BPPE and interaction of storage time and BPPE were not significant ($p > 0.05$). By increasing the storage time, the free fatty acid content of the oil increased non-linearly (Figure 3). According to the results of table 4, the linear parameter of the storage time had the greatest effect on the free fatty acid content of sunflower seed oil. As seen in figure 2, similar to the addition of BPPE, in the commercial sunflower oil increasing the storage time caused to increase in the free fatty acid content ($p < 0.05$). In this study, the free fatty acid content of sunflower oil was 0.09 - 2.24 mg/g. Kehili et al. [19] reported that the addition of tomato peel and seed reduced the free acidity of refined olive oil and sunflower oil. Salami et al. [20] reported that the addition of pumpkin extract obtained with supercritical reduced the acid value of canola oil (Stored at 30 °C for 60 days).

Thiobarbituric acid

In the fatty products that have high oxidation and spoilage, the peroxide value alone is not a suitable indicator. Because it only measures primary oxidation compounds, these products are unstable and turn into secondary oxidation products. Secondary products can be measured with the thiobarbituric acid value. This indicator shows the amount of malondialdehyde as secondary oxidation products. Table 2 shows the best model for fitting the thiobarbituric acid value was the quadratic model ($p = 0.0007$). It can also be seen in table 3, the square parameter of storage time on the thiobarbituric acid value of sunflower oil was significant ($p = 0.0003$), although the effect of BPPE and interaction of storage time and BPPE were not significant ($p > 0.05$). Similar to peroxide value, increasing the storage time up to 8 days, the thiobarbituric acid of the oil increased, however, with increase from 8 to 16 days, the thiobarbituric acid decreased (Figure 4). It seems that from the 8th day onwards, antioxidant and phenolic compounds of BPPE showed their effects better and had decreasing effect on the production of malondialdehyde. These compounds prevent the oxidation process with deterrence of free radicals and decreasing the production of secondary compounds such as malondialdehyde. According to the results of table 4, the interaction parameter of BPPE and storage time had the highest effect on the thiobarbituric acid of sunflower seed oil. In the commercial sunflower seed oil, increasing the storage time didn't have significant effect on the thiobarbituric acid value of oil (Figure 2). The thiobarbituric acid content of sunflower oil was 0.021 - 0.057 mg/kg. Drinić et al. [21] studied the effect of pomegranate peel extract on the stability of pomegranate seed oil. Their results showed that pomegranate peel extract was more effective than BHT and mixture of pomegranate peel extract and BHT to the reduction of thiobarbituric acid value of pomegranate seed oil.

Conjugated dienes

Conjugated dienes are secondary oxidation products that are produced after peroxides. With the extension of the oxidation process, the conjugated dienes are broken and produced ketones and aldehydes as secondary oxidation products. Table 2 shows the best model for fitting the conjugated dienes value was the linear model ($p < 0.0001$). It can also be seen in table 3, the linear parameters of storage time and BPPE on the conjugated dienes of sunflower oil were significant ($p \leq 0.05$). According to the results of table 4, the linear parameter of storage time had the higher effect on the conjugated dienes of sunflower seed oil. Increasing the storage time increased the conjugated dienes sharply, however it was reduced very slow by

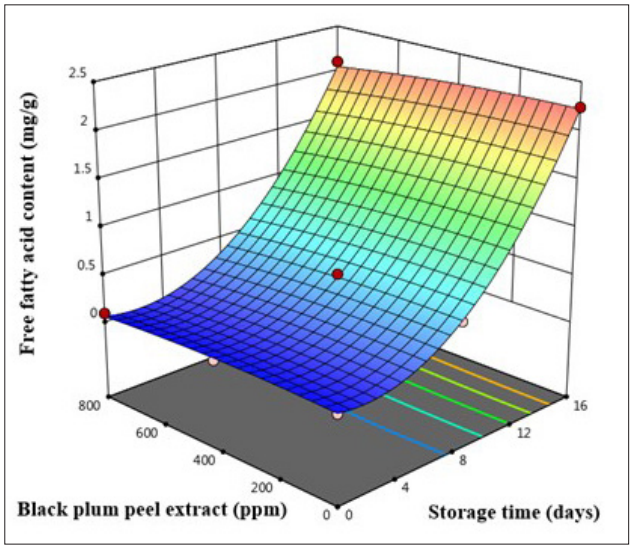

Figure 3: The effect of black plum peel extract and storage time on the free fatty acid content of sunflower seed oil.

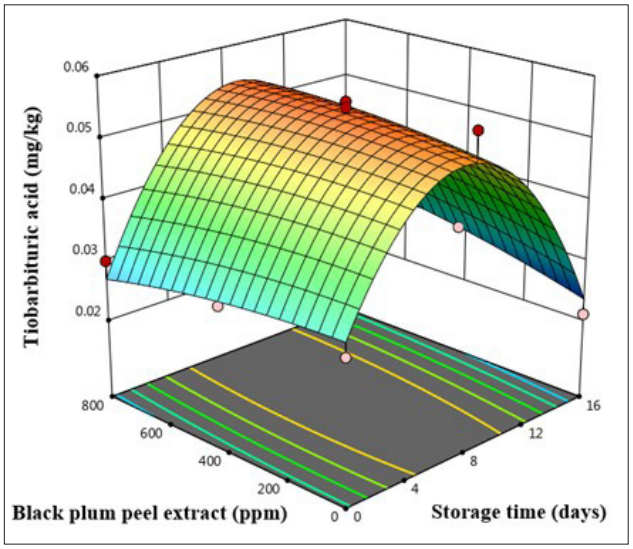

Figure 4: The effect of black plum peel extract and storage time on the thiobarbituric acid of sunflower seed oil.

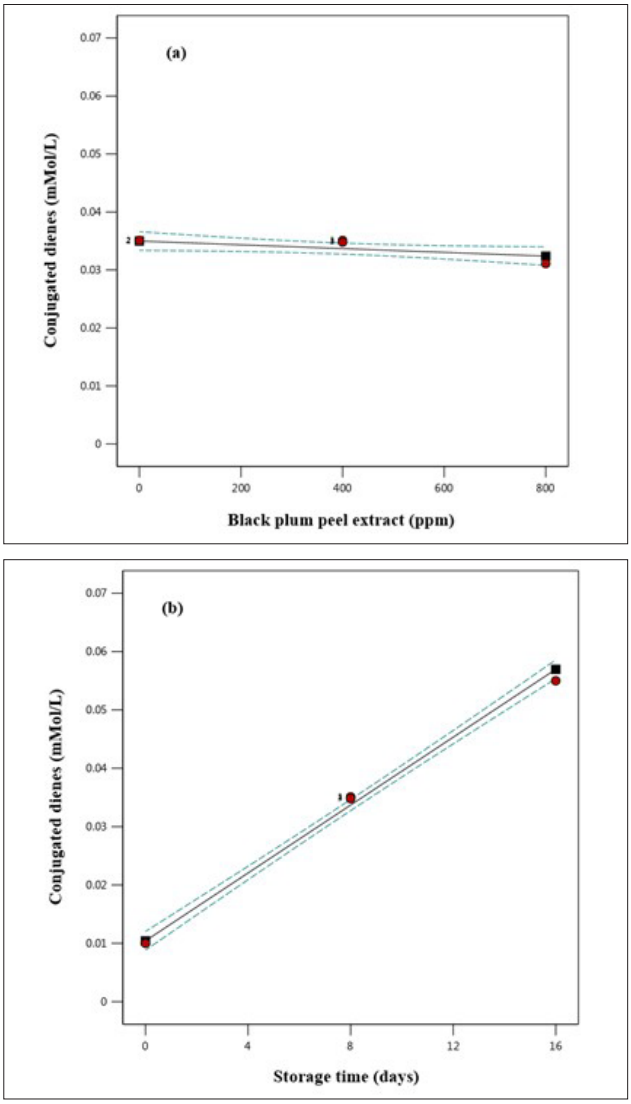

Figure 5: The effect of **(a)** black plum peel extract and **(b)** storage time on the conjugated dienes of sunflower seed oil.

increasing the BPPE (Figure 5). In the commercial sunflower seed oil, increasing the storage time increased the conjugated dienes (Figure 2). The conjugated dienes value of soybean oil was 0.01 - 0.059 m Mol/L. Mohdali et al. [18] in the study of the effect of sesame cake extract on sunflower and soybean oil reported that increasing the storage time, increased the conjugated dienes and trienes. The samples containing sesame cake extract showed lower conjugated dienes and trienes compared to the control. The results showed that the antioxidant activity of sesame cake extract was higher than BHA and BHT and lower than TBHQ. Sultana et al. [22] studied the effect of agro-wastes containing rice bran, rice hull, wheat bran, wheat husk, peels of citrus, banana, apple, and pomegranate on the oxidative stability of corn oil. The oil was heated at 60 °C for 8 h per day and for 30 days. Conjugated dienes and trienes were decreased. Pomegranate peel extract and rice hull extract had the most and the least effect on the conjugated dienes and trienes, respectively.

Carbonyl value

Carbonyl value is a good parameter to measure the oxidation in fatty products. This parameter shows the quality of heated and fried oils. These compounds cause unpleasant taste and flavor and reduce the quality of oils. Table 2 shows that the best model for fitting the carbonyl value was the quadratic model ($p = 0.0001$). It can be seen in table 3, the linear and square parameters of storage time on the carbonyl value of sunflower oil was significant ($p < 0.0001$), although the effect of BPPE and interaction of storage time and BPPE were not significant ($p > 0.05$). Increasing the storage time increased the carbonyl value nonlinearly (Figure 6). Similarly, in commercial sunflower seed oil, the carbonyl value increased with the storage time (Figure 2). Table 4 presents the linear parameter of the storage time had the greatest effect on the carbonyl value of sunflower seed oil. The peroxide value of sunflower oil was in the range of 0.56 - 1.452 meq/kg. Salami et al. [20] studied the effect of water extracts from subcritical water (SWE) and ethanol or water extracts from supercritical CO_2 (SFE) of pumpkin peel on the quality of canola oil. The oil was heated at 30 °C for 60 days. The mix of SFE and SWE was more effective on the reduction of carbonyl value.

Optimizing the addition of BPPE on sunflower oil during the storage time

Considering that the addition of BPPE on sunflower oil during the storage time was set at special condition (BPPE 0 - 800 ppm and 0 - 16 storage time), the best conditions for oxidative stability of sunflower oil in order to reach the best quality determined. According to the results, the best conditions for sunflower oil were 3 days and 472.73 ppm BPPE concentration ($R^2 = 0.71$). In order to investigate the models predicted by the software, the data obtained from the software in optimal conditions compared and evaluated with the same characteristics in real conditions (Table 4). As can be seen, the optimal predicted contents for all characteristics were agreed with the predicted conditions.

Conclusion

The effect of BPPE concentration as natural antioxidant and storage time on the oxidative stability of sunflower oil was

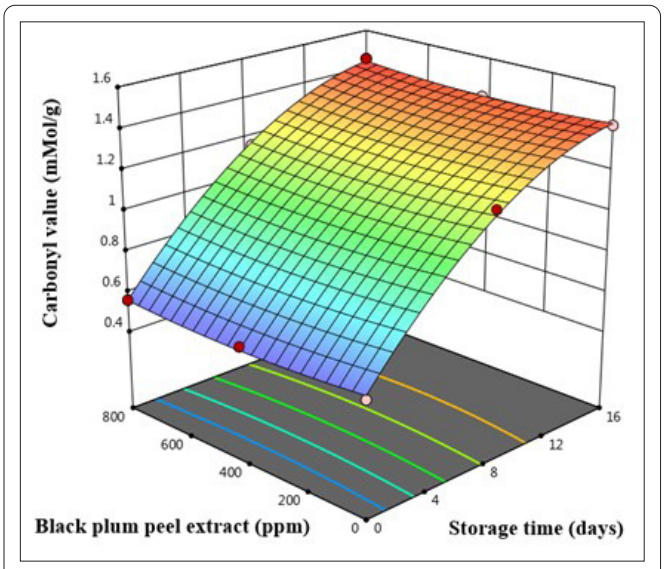

Figure 6: The effect of black plum peel extract and storage time on the carbonyl value of sunflower seed oil.

studied. Increasing the storage time up to 8 days caused to increase the peroxide value and thiobarbituric acid of the oil and there were reduced from 8 to 16 days. It seems that after 8 days, antioxidant and phenolic compounds of BPPE had the best effect on the reduction of peroxide value and thiobarbituric acid value. Increasing the storage time increased the conjugated dienes sharply, however it was reduced very slow by increasing the black plum peel extract. Free fatty acid content and carbonyl value of the oil increased non-linearly by the storage time. The RSM was effective and usable for determining the optimal concentration of BPPE for oxidative stability of sunflower oil.

Acknowledgements

None.

Conflict of Interest

None.

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References

1. Chen X, Zhang Y, Zu Y, Yang L, Lu Q, et al. 2014. Antioxidant effects of rosemary extracts on sunflower oil compared with synthetic antioxidants. *Int J Food Sci Technol* 49(2): 385-391. https://doi.org/10.1111/IJFS.12311
2. Kozłowska M, Gruczyńska E. 2018. Comparison of the oxidative stability of soybean and sunflower oils enriched with herbal plant extracts. *Chem Zvesti* 72: 2607-2615. https://doi.org/10.1007/s11696-018-0516-5
3. Sadoudi R, Ammouche A, Ali AD. 2014. Thermal oxidative alteration of sunflower oil. *African J Food Sci* 8(3): 116-121. https://doi.org/10.5897/AJFS12.112
4. Carelli AA, Franco IC, Crapiste GH. 2005. Effectiveness of added natural antioxidants in sunflower oil. *Grasas Aceites* 56(4): 303-310. https://doi.org/10.3989/GYA.2005.V56.I4.97
5. Bharti R, Singh B. 2020. Green tea (*Camellia assamica*) extract as an antioxidant additive to enhance the oxidation stability of biodiesel synthesized from waste cooking oil. *Fuel* 262: 116658. https://doi.org/10.1016/j.fuel.2019.116658
6. Blasi F, Cossignani L. 2020. An overview of natural extracts with antioxidant activity for the improvement of the oxidative stability and shelf life of edible oils. *Processes* 8(8): 956. https://doi.org/10.3390/pr8080956
7. Drinić Z, Mudrić J, Zdunić G, Bigović D, Menković N, et al. 2020. Effect of pomegranate peel extract on the oxidative stability of pomegranate seed oil. *Food Chem* 333: 127501. https://doi.org/10.1016/j.foodchem.2020.127501
8. Tinello F, Lante A. 2020. Accelerated storage conditions effect on ginger-and turmeric-enriched soybean oils with comparing a synthetic antioxidant BHT. *LWT* 131: 109797. https://doi.org/10.1016/j.lwt.2020.109797
9. Zahid MA, Choi JY, Seo JK, Parvin R, Ko J, et al. 2020. Effects of clove extract on oxidative stability and sensory attributes in cooked beef patties at refrigerated storage. *Meat Sci* 161: 107972. https://doi.org/10.1016/j.meatsci.2019.107972
10. Elsayed N, Hammad KS, Abd El-Salam EA. 2020. Plum (*Prunus domestica* L.) leaves extract as a natural antioxidant: extraction process optimization and sunflower oil oxidative stability evaluation. *J Food Proc Pre* 44(10): e14813. https://doi.org/10.1111/jfpp.14813
11. Mohammadi-Moghaddam T, Firoozzare A, Kariminejad M, Sorahi M, Tavakoli Z. 2020. Black plum peel as a useful by-product for the production of new foods: chemical, textural, and sensory characteristics of Halva Masghati. *Int J Food Prop* 23(1): 2005-2019. https://doi.org/10.1080/10942912.2020.1835953
12. Kariminejad M, Naimabadi A, Morshedi A, Mohammadi-Moghaddam T, Shokuhi A, et al. 2023. Oxidative stability of sunflower and soybean oils enriched with black plum peel extract in comparison with synthetic antioxidants. *PloS One* 18(1): e0279735. https://doi.org/10.1371/journal.pone.0279735
13. Pei X-C, Liu YX, Liu HL, Li DY, Yin FW, et al. 2022. Improving the oxidation stability of high-oleic sunflower oil with composite antioxidants. *J Food Bioact* 18(18): 90-97. https://doi.org/10.31665/JFB.2022.18312
14. Delfanian M, Kenari RE, Sahari MA. 2016. Effect of natural extracted antioxidants from *Eriobotrya japonica* (Lindl.) fruit skin on thermo oxidative stability of soybean oil during deep frying. *Int J Food Prop* 19(5): 958-973. https://doi.org/10.1080/10942912.2015.1041039
15. Umeda WM, Jorge N. 2021. Oxidative stability of soybean oil added of purple onion (*Allium cepa* L.) peel extract during accelerated storage conditions. *Food Control* 127: 108130. https://doi.org/10.1016/J.FOODCONT.2021.108130
16. Romeo R, De Bruno A, Imeneo V, Piscopo A, Poiana M. 2020. Impact of stability of enriched oil with phenolic extract from olive mill wastewaters. *Foods* 9(7): 856. https://doi.org/10.3390/foods9070856
17. More SB, Gogate PR, Waghmare JS. 2021. Bioactives from pomegranate peel and moringa leaves as natural antioxidants for stability of edible oil blends. *Braz J Chem Eng* 39: 527-538. https://doi.org/10.1007/s43153-021-00150-1
18. Mohdaly AA, Smetanska I, Ramadan MF, Sarhan MA, Mahmoud A. 2011. Antioxidant potential of sesame (*Sesamum indicum*) cake extract in stabilization of sunflower and soybean oils. *Ind Crops Prod* 34(1): 952-959. https://doi.org/10.1016/J.INDCROP.2011.02.018
19. Kehili M, Choura S, Zammel A, Allouche N, Sayadi S. 2018. Oxidative stability of refined olive and sunflower oils supplemented with lycopene-rich oleoresin from tomato peels industrial by-product, during accelerated shelf-life storage. *Food Chem* 246: 295-304. https://doi.org/10.1016/j.foodchem.2017.11.034
20. Salami A, Asefi N, Kenari RE, Gharekhani M. 2021. Extraction of pumpkin peel extract using supercritical CO_2 and subcritical water technology: enhancing oxidative stability of canola oil. *J Food Sci Technol* 58(3): 1101-1109. https://doi.org/10.1007/s13197-020-04624-x
21. Drinić Z, Mudrić J, Zdunić G, Bigović D, Menković N, et al. 2020. Effect of pomegranate peel extract on the oxidative stability of pomegranate seed oil. *Food Chem* 333: 127501. https://doi.org/10.1016/j.foodchem.2020.127501
22. Sultana B, Anwar F, Asi MR, Chatha SA. 2008. Antioxidant potential of extracts from different agro wastes: stabilization of corn oil. *Grasas Aceites* 59(3): 205-217. https://doi.org/10.3989/GYA.2008.V59.I3.510