

***Berberis crataegina* DC. as a novel natural food colorant source: ultrasound-assisted extraction optimization using response surface methodology and thermal stability studies**

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Abstract

This study aimed to investigate the potential use of anthocyanin of *Berberis crataegina* DC. as a natural food coloring agent in the food industry. For this aim, the ultrasound-assisted extraction (UAE) method was performed to extract anthocyanin of *Berberis crataegina* DC. The effect of ultrasound power (X_1 : 20-100%), extraction temperature (X_2 : 20-60 °C), and time (X_3 : 10-20 min) on TPC and TAC of *Berberis crataegina* DC. extracts were examined and optimized by applying the Box–Behnken experimental design (BBD) with the response surface methodology (RSM). The influence of three independent variables and their combinatorial interactions on TPC and TAC were investigated by the quadratic models (R^2 : 0.9638&0.9892 and adj R^2 : 0.9171&0.9654, respectively). The optimum conditions were determined as the amplitude level of 98%, the temperature of 57.41 °C, and extraction time of 13.86 min. The main anthocyanin compounds were identified, namely, Delphinidin-3-O-galactoside, Cyanidin-3-O-glucoside, Cyanidin-3-O-rutinoside, Petunidin-3-O-glucoside, Pelargonidin-3-O-glucoside, and Peonidin-3-O-glucoside. The anthocyanin degradation showed first-order kinetic, degradation rate constant (k), the half-life values ($t_{1/2}$), and loss (%) were significantly affected by different temperatures ($P < 0.05$). Higher degradation (k) in anthocyanin content was observed at 90 °C. This study suggested that UAE is an efficient method for the extraction of TPC and TAC from *Berberis crataegina* DC.

Keywords: *Berberis crataegina* DC., ultrasound-assisted extraction, box-behnken experimental design, anthocyanin, natural food colorant.

Practical Application: The ultrasound-assisted extraction optimization of *Berberis crataegina* DC.

1 Introduction

Berberis crataegina DC. are fruits of wild plant belongs to the Berberidaceae family, grown commonly in the Anatolia region of Turkey. The *Berberis crataegina* DC. are consumed widely in raw and or after being processed into natural juices, marmalades, and jellies, and dried in the sun (Akbulut et al., 2009; Işıklı & Yılmaz, 2014; Motaleb et al., 2005). The color of *Berberis crataegina* DC. varies from dark purple to black and their tastes are slightly sour due to the berberine content of fruits (Baytop, 1963; Eroğlu et al., 2020; Siow et al., 2011). The *Berberis crataegina* DC. has organic acids, high content of vitamin C, tannins, and high anthocyanin content. Therefore, they have a strong antifungal activity and anti-inflammatory, antipruritic, and diuretic effects antioxidant and free radical scavenging properties due to phenolic compounds especially anthocyanin (Ullah et al., 2015; Yeşilada & Küpeli, 2002). Several investigations have been conducted to evaluate the phenolic compounds, antioxidant activities, and organic acid contents of *Berberis crataegina* DC. (Charehsaz et al., 2015; Gulsoy et al., 2011), which is rich in polyphenols (Eroğlu et al., 2020) and anthocyanin content. However, no study has been conducted on potential use of natural colorant of anthocyanin extracted from *Berberis crataegina* DC. The anthocyanin naturel colorant (Brouillard et al., 1982). The anthocyanin stability is mostly influenced by temperature, pH, chemical structure, and light

(Castañeda-Ovando et al., 2009). Therefore, the extraction of anthocyanins is a crucial step for the isolation, identification, and use of anthocyanin as a food colorant.

Extraction techniques applied for bioactive compounds recovery from fruits and plants may differ considering the extraction yield and production cost. Traditional extraction methods require a significant amount of energy and solvent, and an intensive labor force. Also, these methods can degrade thermally sensitive compounds such as anthocyanin (Sharifi & Hassani, 2012). The UAE method shortens the extraction time and energy requirements as compared to conventional extraction methods. Also, the UAE method provides the recovery of bioactive compounds through the action of acoustic cavitation generated by an ultrasound wave in the solvent, and the enhancement of mass transport by disrupting the plant cell walls (Dranca & Oroian, 2016; Li et al., 2019; Riciputi et al., 2018; Rodrigues et al., 2015). On the other hand, the UAE efficiency is affected by several parameters such as ultrasound amplitude, extraction time, temperature, solvent-sample ratio, and pH (Chemat et al., 2017). Therefore, the optimization of the extraction process is necessary to obtain high-yield and high-quality bioactive compounds. For the optimization, the effects of the selected parameters on the extraction efficiency analyze through a Box–Behnken experimental design (BBD)

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with a response surface methodology (RSM), which consists of mathematical techniques to maximize the analytical response (Ding et al., 2016; Li et al., 2019). However, to the best of our knowledge, there is no literature on the UAE of TPC and TAC from *Berberis crataegina* DC. Also, it is necessary to optimize the conditions of the UAE of *Berberis crataegina* DC. to determine the potential use as a natural food coloring agent because there is no study about the potential sources of natural food coloring agents of *Berberis crataegina* DC. for the food industry. However, the chemical structure of anthocyanin pigments is not stable and they are susceptible to degradation during thermal processing (Kara & Erçelebi, 2013). Therefore, it is essential to determine the kinetic parameters for prediction of the quality changes.

The food industry uses food coloring agents to determine the acceptability of processed food to consumers. Okafor et al. (2016) studied about the development of the global food coloring market. They stated that the demand for food color agents in the global market in 2000 was 2400 Metric Tons, and it was expected to increase to 15.000 Tons in 2015. However, there is a growing demand for natural food color agents as there is a growing concern about the health effects of the use of synthetic food color agents in human diets. Therefore, the UAE of TPC and TAC from *Berberis crataegina* DC. was studied for the determination of the potential of new source of the natural food colorant. The objective of the study is to investigate the optimum extraction conditions of independent variables, namely the ultrasound amplitude, extraction temperature, and time using RSM and to determine the thermal stability of the anthocyanin.

2 Material and method

In this study, *Berberis crataegina* DC. grown under natural conditions without cultivation in Tunceli province was collected in August. The collected fruits were transferred to the laboratory then cleaned and stored in a refrigerator at 4 °C until analysis. The chemicals used in the study were obtained from Merck (Merck, Darmstadt, Germany).

2.1 Experimental Design of Extraction

A three-level Box–Behnken experimental design (BBD) with a response surface methodology (RSM) was performed to optimize the ultrasound-assisted extraction (UAE) conditions of *Berberis crataegina* DC. (Fernandez-Barbero et al., 2019). In this experimental design, three independent variables at three different levels, i.e., (–1) low, (0) medium, and (+1) high, were studied. The independent variables and their levels of the BBD were given in Table 1. In determining these specific ranges of values, we have benefited from the existing knowledge on the extraction of phenolic compounds and anthocyanins previously studied (Karasu et al., 2019; Skrypnik & Novikova, 2020). The response variables were TPC and TAC of the *Berberis crataegina* DC. Seventeen different experimental points with three center points for each of the three replicates were performed.

2.2 UAE Procedure of *Berberis crataegina* DC

In the UAE procedure, *Berberis crataegina* DC. were extracted by using an ultrasonic bath (WiseClean, DH.WUC.D10H,

Table 1. Independent variables and levels of variables for the Box–Behnken design.

Symbols	Independent Variables	Levels		
		–1	0	+1
X ₁	Power, A	20	60	100
X ₂	Temperature, °C	20	40	60
X ₃	Time, min	10	15	20

Germany—40 kHz, 258 W) continuously. *Berberis crataegina* DC. (5 mg) were extracted with 50 ml methanol-water (80:20) according to the conditions specified in the experimental design (Table 1) and homogenized by Ultra-Turrax (Daihan, HG-15D, South Korea) at 10,000 rpm for 3 min. Then, the extracted samples were centrifuged at 4500 rpm and the centrifuged samples were first roughly filtered and then filtered through 0.25 µm filters. The obtained extracts were stored at 4 °C until further analysis (Gazeran et al., 2016).

2.3 Determination of TPC and TAC of *Berberis crataegina* DC

TPC in *Berberis crataegina* DC. extracts was determined with Folin–Ciocalteu method (Singleton & Rossi, 1965). The absorbance values were measured at 765 nm (UV-3600, Shimadzu, Kyoto, Japan). TPC was expressed as mg gallic acid equivalent per 100-gram.

TAC in *Berberis crataegina* DC. extracts was determined by using the pH differential method (Fuleki & Francis, 1968). Absorbance values were measured at 517 nm with a spectrophotometer (UV-3600, Shimadzu, Kyoto, Japan). TAC was expressed as mg per L.

2.4 Determination of the phenolic acid and anthocyanin profile of *Berberis crataegina* DC

Individual phenolic acid and anthocyanin profile of ultrasound-assisted *Berberis crataegina* DC. extracts were identified by HPLC coupled to a diode array (HPLC-DAD, Shimadzu Corp., Kyoto, Japan). The extracts were obtained for TPC and TAC analysis and they were filtered through a 0.45-µm membrane filter. Then, 1 ml of the filtered sample was analyzed in an HPLC system (LC-20AD pump, SPD20A DAD detector, SIL-20A HT autosampler, CTO-10ASVP column oven, DGU-20A5R degasser, and CMB-20A communications bus module (Shimadzu Corp., Kyoto, Japan). Separations were conducted at 40 °C on a reversed-phase column (Intersil® ODS C-18, GL Sciences, Tokyo, Japan) with a 250mm×4.6mm length, 5 µm particle size. The mobile phases were solvent A (distilled water with 0.1% (v/v) acetic acid) and solvent B (acetonitrile with 0.1% (v/v) acetic acid). The flow rate was set as 1 mL/min and the chromatograms were recorded at 254–356 nm. Twelve phenolic acids as standards, 4-Hidroksibenzoik acid, Coumaric acid, Cinnamic acid, Syringic acid, Vanillic acid, Chlorogenic acid, Ferulic acid, Sinapinic acid, Gentisic acid, Trans-3-hydroxy cinnamic acid, Caffeic acid, and Gallic acid, were used for phenolic acids separation and quantification. Also, six anthocyanins as standards, Delphinidin-3-O-galactoside, Cyanidin-3-O-glucoside, Cyanidin-3-O-rutinoside, Petunidin-3-O-glucoside,

Pelargonidin-3-O-glucoside, Peonidin-3-O-glucoside, were used for anthocyanins separation and quantification. The result of individual phenolic acid and anthocyanin amounts were expressed as mg/100 g.

2.5 Thermal degradation kinetics of anthocyanin

The thermal stability of anthocyanin from *Berberis crataegina* DC. was studied at 70, 80, and 90 °C (Wang & Xu, 2007). The anthocyanin content was determined for every 1 h interval. The thermal degradation data were fitted to the exponential kinetic model to determine the first-order kinetics behavior of the anthocyanin of *Berberis crataegina* DC. by Equation 1:

$$C = C_0 \times \exp(-k \times t) \quad (1)$$

where C_0 is the initial anthocyanin content, C is the anthocyanin concentration of *Berberis crataegina* DC. after heating at a given temperature, and k is the constant for the first-order kinetic model. Half-time ($t_{1/2}$) was calculated using Equation 2 as the following:

$$t_{1/2} = \ln\left(\frac{0.5}{k}\right) \quad (2)$$

2.6 Statistical analysis

All experiments were carried out in triplicates. The experimental results were expressed as means \pm standard deviation. A one-way ANOVA test was used in the SPSS program. Duncan's multiple test range was applied for comparisons of means. A probability level of $p < 0.05$ was considered statistically significant.

3 Results and discussion

3.1 UAE of *Berberis crataegina* DC

TPC and TAC extraction from *Berberis crataegina* DC. was performed using ultrasonic treatment (20, 60, and 100 A, respectively) by varying temperature (20, 40, and 60 °C) and extraction time (10, 15, and 20 min) for the optimization of extraction yield. The experiment was conducted in seventeen runs to investigate the effect of the selected variables on TPC and TAC values obtained under different experimental conditions were presented in Table 2.

Our results showed that TPC values ranged from 10.76 to 62.95 mg/100 g and TAC values ranged from 785.234 to 2659.297 mg/L. The highest TPC (more than 34 mg/100 g) and TAC (more than 2000 mg/L) values were obtained at 100 A ultrasound power, and 40 and 60 °C. Ghafoor et al. (2009) studied the experimental values of total phenols, antioxidant activities, and anthocyanins of grape seed extract obtained by UAE at the experimental conditions (ethanol concentration, extraction time, and temperature) in eighteen runs. Also, Bing et al. (2019) studied that the ultrasound-assisted extraction (UAE) of sheep abomasum protein concentrates (SAPC) and the investigation of the properties of SAPC. They reported that the highest yield and protein values in SAPC obtained by the UAE were $24.41 \pm 0.71\%$ and 92.36 ± 3.80 g/100 g, respectively.

Table 2. Experimental values of TPC and TAC of *Berberis crataegina* DC. obtained from Box-Behnken design.

Run*	X_1	X_2	X_3	TPC (mg/100g)	TAC (mg/L)
1	20	20	10	10.76	785.234
2	60	20	15	15.64	1593.909
3	100	60	10	42.89	2076.506
4	20	60	10	16.77	1087.932
5	20	40	15	14.33	1524.480
6	100	40	15	46.31	2247.670
7	20	20	20	11.44	1004.440
8	60	40	15	23.20	1967.380
9	100	40	10	34.04	2020.500
10	60	40	15	24.83	1658.199
11	100	40	20	62.95	2463.980
12	60	60	15	28.60	1999.691
13	60	40	15	22.21	1654.859
14	100	60	20	57.87	2659.297
15	20	60	20	11.68	1190.630
16	60	40	10	20.24	1291.993
17	60	40	20	30.82	1670.140

*Run number was used for identification purposes only and does not indicate the order in which the experimental runs were conducted.

The quadratic model modeled the influence of the employed parameters on TAC and TPC extraction, as well as the interactions between parameters were presented in Table 3.

Estimated coefficients of the linear, quadratic, and interaction factors of the polynomial equations and their significance (p-values) were evaluated. According to Table 3, the linear and quadratic terms were highly significant ($P < 0.01$). The lack of fit was used to verify the adequacy of the model and was not significant ($P > 0.05$), indicating that the model could adequately fit the experiment data. All individual parameters significantly affected TPC and TAC ($P < 0.1$). According to Table 3, R^2 and adj R^2 values were 0.9892 and 0.9654 for TPC and 0.9638 and 0.9171 for TAC, and the lack of fit was insignificant ($P > 0.1$). This result indicated that the quadratic model successfully described the effect of extraction process parameters on TPC and TAC. In contrast, the interaction between the ratio of ultrasound power and extraction temperature (X_1X_2), the quadratic term of extraction temperature (X_2^2), and the quadratic term of extraction time (X_3^2) were not significant. According to Table 3, the model parameters of ultrasound power showed a smaller P-value and significant effect on the TPC and TAC. Therefore, optimization of ultrasound power is an important step. Chen et al. (2007) reported that the change of ultrasonic power and extraction time had a significant effect on the TAC of red raspberries extracts. In our study, at a low level of extraction time (13.86) and temperature (57.41 °C), maximum desirability was obtained.

Three-dimensional response surface plots, which showed the effect of process parameters and the interaction of these parameters on TPC, were presented in Figure 1. There is a linear increase in TPC with an increase in extraction time at a fixed amplitude and temperature (Figure 1b, c).

Ramić et al. (2015) similarly reported that the ultrasound-assisted extracts of polyphenolic compounds from Aronia

melanocarpa by-products from filter-tea factory had a higher yield of TPC as the extraction time increased. It is noticeable that the ultrasound power dominantly affects TPC comparing to extraction time and temperature, by analyzing the slopes for each variable.

Figure 2 showed the response surface plots of multiple influences of all independent variables that confirmed the mathematical analysis of UAE of TAC. Figure 2b, c showed a linear increase in TAC with an increase in extraction time at a

fixed ultrasound power and temperature. Similarly, there is a linear increase in TAC with an increase in extraction temperature from 20 °C to 60 °C at a fixed ultrasound power and time and with an increase in ultrasound power at a fixed extraction time and temperature. This positive quadratic effect of temperature on TAC can be explained that the increase of temperature can accelerate the molecular mass transfer, the conductivity of the solution to the plant material. Therefore, the influence of temperature can increase the solubility and diffusivities of the

Table 3. ANOVA for the response surface quadratic model.

Regression coefficients	df	TPC			TAC		
		Mean square	F	p	Mean square	F	p
Model ^v	9	455.64	71.54	<0.0001	4.68×10 ⁵	20.68	0.0003
X ₁ -Power	1	1482.74	232.81	<0.0001	1.57×10 ⁶	69.66	<0.0001
X ₂ -Temperature	1	91.22	14.32	0.0069	1.84×10 ⁵	8.14	0.0246
X ₃ -Time	1	281.55	44.21	0.0003	2.83×10 ⁵	12.50	0.0095
Cross product							
X ₁ X ₂	1	18.52	2.91	0.1319	1.96×10 ⁴	0.87	0.3830
X ₁ X ₃	1	324.01	50.87	0.0002	5.99×10 ⁴	2.65	0.1478
X ₂ X ₃	1	32.56	5.11	0.0582	594.71	0.026	0.8759
Quadratic							
X ₁ ²	1	108.67	17.06	0.0044	4.36×10 ⁴	1.93	0.2076
X ₂ ²	1	22.84	3.59	0.1001	8791.76	0.39	0.5532
X ₃ ²	1	5.24	0.82	0.3944	2.29×10 ⁵	10.13	0.0154
Lack of fit	5	8.22	4.69	0.1850	1.8×10 ⁴	0.59	0.7281
R ²		0.9892			0.9638		
Adj-R ²		0.9654			0.9171		

^vdf degree of freedom values of “Prob > F” less than 0.05 indicate model terms are significant.

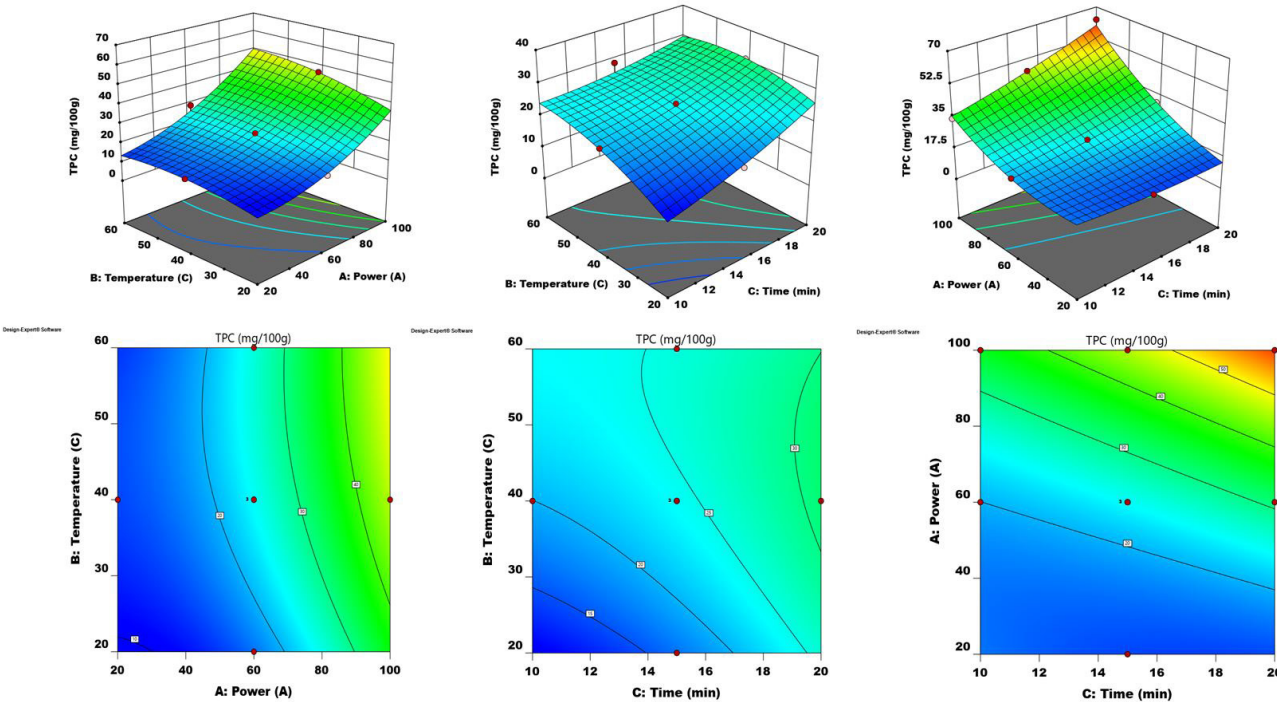


Figure 1. 3 D surface and counterplot for TPC.

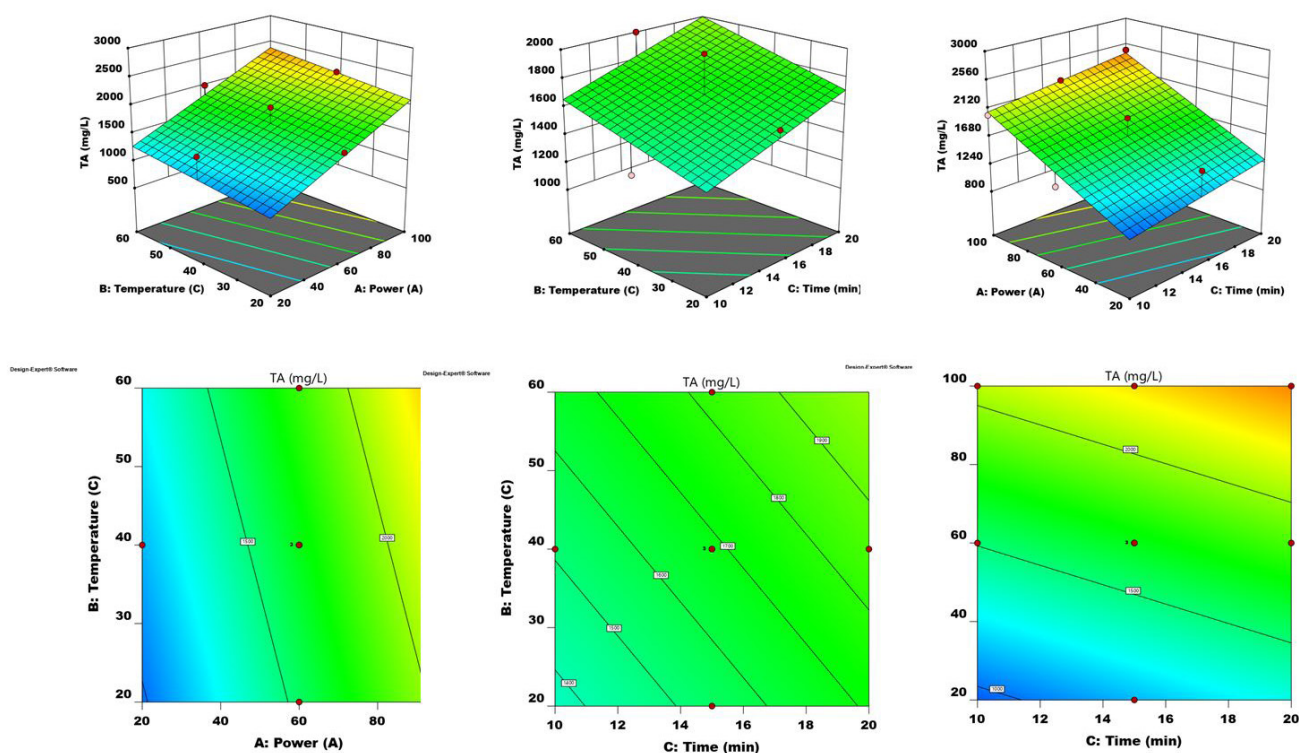


Figure 2. 3 D surface and counterplot for TAC.

plant materials into the solution so that the extraction yield can increase (Yang et al., 2010). Also, the temperature has a greater effect on the cavitation threshold, which causes acoustic cavitation and results in cavitation core formation. The effect of the relatively greater shear force shattered and exploded the cavitation nucleus formed and broke cell walls during extraction, which increased the mass transfer rate (Toma et al., 2001) and increased extraction efficiency (Figure 2a,b).

As can be seen in Figure 2, the ultrasound power dominantly influences TAC comparing to extraction temperature and time, by analyzing the slopes for each variable (Figure 2a, c). Therefore, it is expected that the upper level of power (100A) will be optimal for the extraction of TAC. Ghafoor et al. (2009) observed that a linear increase in total anthocyanin contents with an increase in extraction temperature on grape seed anthocyanins at a fixed ethanol concentration (50%).

3.2 Optimization of extraction parameters

The statistical optimization of UAE of TPC and TAC was performed by using the RSM-generated model. Celli et al. (2015) was preferred this model for the optimization of TAC of haskap berries. In this study, ultrasonic treatment (20, 60, and 100 A, respectively), extraction temperature (20, 40, and 60 °C), and extraction time (10, 15, and 20 min) were selected as factors. The optimum extraction conditions were determined based on the maximum response of TPC and TAC of *Berberis crataegina* DC. extracts obtained by UAE according to the quadratic regression equation obtained from the Design Expert 7.0 software program. The optimum extraction parameters were determined as 57.41 °C,

13.86 min, and 98.00 amplitude levels. TPC and TAC were also determined experimentally for verification of statistical results at the experimental point. Arici et al. (2016) determined that the optimum extraction temperature and time combination for tulip anthocyanin were 54 °C and 116 min.

3.3 Phenolic acid and anthocyanin profile of the optimized extract

Table 4 showed the concentration of phenolic compounds obtained from UAE of *Berberis crataegina* DC. extract prepared at the optimal conditions. Six anthocyanin compounds were identified, namely Delphinidin-3-O-galactoside (82.05 mg/100g), Cyanidin-3-O-glucoside (85.48 mg/100 g), Cyanidin-3-O-rutinoside (49.35 mg/100 g), Petunidin-3-O-glucoside (1.48 mg/100 g), Pelargonidin-3-O-glucoside (21.93 mg/100 g) and Peonidin-3-O-glucoside (50.91 mg/100g) were determined. Although different fruits and vegetables contain different anthocyanin compounds, the predominant anthocyanins include in fruits and vegetables are cyanidin-3-O-glucoside, delphinidin-3-O-glucoside, malvidin-3-O-glucoside, pelargonidin-3-O-glucoside, and petunidin-3-O-glucoside (Patras et al., 2010). Commercial anthocyanins, namely cyanidin 3-glucoside, pelargonidin 3-glucoside and peonidin 3-glucoside have been used to obtain color varied from red to purple and blue color (Martins et al., 2016). Therefore, *Berberis crataegina* DC. may be evaluated as a new source of food colorant in the food industry. Celli et al. (2015) determined that five anthocyanins of the optimized extract obtained by UAE in haskap berries were identified, namely cyanidin 3,5-diglucoside, cyanidin 3-glucoside, cyanidin 3-rutinoside, pelargonidin 3-glucoside, and peonidin 3-glucoside. As shown in Table 4, Cyanidin-3-O-glucoside

Table 4. The concentration of phenolic compounds obtained from optimum conditions of UAE of *Berberis crataegina* DC.

Anthocyanin	mg/100g
Delphinidin-3-O-galactoside	82.05
Cyanidin-3-O-glucoside	85.48
Cyanidin-3-O-rutinoside	49.35
Petunidin-3-O-glucoside	1.48
Pelargonidin-3-O-glucoside	21.93
Peonidin-3-O-glucoside	50.91
Phenolic acid	mg/100g
4-Hidroksibenzoik acid	<0.05
Coumaric acid	0.05
Cinnamic acid	<0.05
Syringic acid	0.54
Vanillic acid	<0.05
Chlorogenic acid	122.45
Ferulic acid	<0.05
Sinapinic acid	<0.05
Gentisic acid	0.19
Trans-3-hydroxy cinnamic acid	<0.05
Caffeic acid	0.26
Gallic acid	0.11

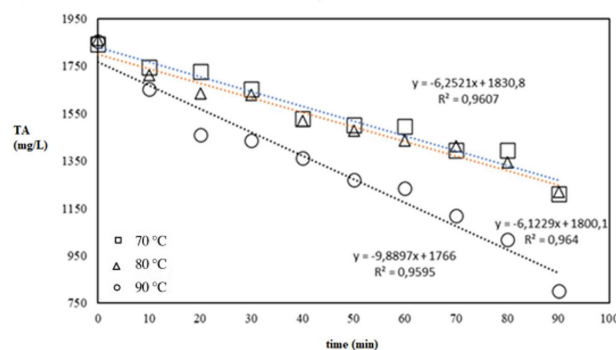
(85.48 mg/100 g) was determined as the major anthocyanin of *Berberis crataegina* DC. while Petunidin-3-O-glucoside (1.48 mg/100 g) was determined as a minor anthocyanin of *Berberis crataegina* DC. A similar result was reported for red onions by Patras et al. (2010). Major anthocyanin was identified as cyanidin 3-glucoside for red onions while minor anthocyanins were delphinidin 3-glucoside and petunidin glucoside.

Twelve phenolic acids were identified, namely 4-Hidroksibenzoik acid, Coumaric acid, Cinnamic acid, Syringic acid, Vanillic acid, Chlorogenic acid, Ferulic acid, Sinapinic acid, Gentisic acid, Trans-3-hydroxy cinnamic acid, Caffeic acid, and Gallic acid. Chlorogenic acid (122.45 mg/100) was determined as major. Mazza et al. (2019) identified that the main phenolic acids found in Syrah grape skin were catechin, epicatechin, quercetin, gallic acid, and p-coumaric acid. Also, the extract of Syrah grape skin was found richer in catechin and epicatechin.

3.4 The temperature stability of anthocyanin

Figure 3 shows the thermal degradation curves of *Berberis crataegina* DC. anthocyanins. The kinetic parameters of *Berberis crataegina* DC. anthocyanin degradation during heating was shown in Table 5. Previous studies showed the thermal degradation of anthocyanins followed the first-order reaction kinetics (Garzon & Wrolstad, 2002; Wang & Xu, 2007; Yang et al., 2008). The coefficients of determination (R^2) values were between 0.959 and 0.964. As expected, the degradation of anthocyanin increased with increasing temperature from 70 °C to 90 °C.

The k values were $0.407 \times 10^2 \text{ min}^{-1}$, $0.522 \times 10^2 \text{ min}^{-1}$, and $0.866 \times 10^2 \text{ min}^{-1}$ at 70, 80 and 90 °C, respectively. The increase of k value with increasing temperature was explained that anthocyanin degradation was greatly dependent on temperature (Kirca et al., 2003). Yang et al. (2008) reported that the

**Figure 3.** Thermal degradation curves of anthocyanins in *Berberis crataegina* DC. at 70, 80, and 90 °C.**Table 5.** Degradation kinetic parameters of anthocyanin in *Berberis crataegina* DC.

Temperature (°C)	k * 10 ² (min ⁻¹)	t _{1/2} (min)	R ²	Loss (%)
70	0.407 ^c	170.045 ^a	0.960	33.607 ^c
80	0.512 ^b	135.297 ^b	0.964	36.399 ^b
90	0.866 ^a	80.018 ^c	0.959	56.765 ^a

^aDifferent lowercase in the same column indicates the significant effect of temperature on k, t_{1/2} value, and loss (%) (p < 0.05).

coefficients of determination (R^2) values were between 0.937 and 0.974 and the degradation rate of aqueous anthocyanins of purple corn cob increased with increased temperature from 70 °C to 90 °C.

As shown in Table 5, the half-life time ($t_{1/2}$) values ranged from 170.045 min to 80.018 min with increasing temperature. Wang and Xu (2007) determined that $t_{1/2}$ values for thermal degradation of blackberry anthocyanins were decreased from 8.8h (528 min) to 2.9h (174 min) by increasing temperature from 90 °C to 70 °C while Yang et al. (2008) reported that $t_{1/2}$ values for thermal degradation of purple corn cob were ranged from 11.6h (696 min) to 7.5h (450 min). The results might have shown that *Berberis crataegina* DC. anthocyanins were less stable to high temperatures as compared to anthocyanins of blackberry and purple corn cob due to their varying anthocyanin composition.

Loss of *Berberis crataegina* DC. anthocyanin were 33.607%, 36.399%, and 56.765% at 70, 80, and 90 °C, respectively (Table 5). The magnitude and duration of heating, the combination of unit operations involving heat, and the inclusion of a blanching step for the prevention of enzyme degradation affect strongly the stability of anthocyanin (Patras et al., 2010).

4 Conclusion

This paper presents the results of the optimization of UAE of TPC and TAC from *Berberis crataegina* DC., and the thermal stability of anthocyanin content of *Berberis crataegina* DC. Also, the potential use as a natural food colorant was evaluated according to findings of the extraction and thermal stability. Ultrasonic waves can efficiently improve the extraction of bioactive

compounds. UAE parameters significantly affected TPC and TAC. The RSM was successfully employed to optimize the extraction and the experimental parameters (ultrasound power, extraction temperature, and time) have been evaluated. This study suggested that anthocyanin content could be increased at 100% ultrasound power, and 40 and 60 °C. Also, the degradation of anthocyanin during the thermal process followed first-order reaction kinetics and the degradation rate increased as temperature increased. The percentage loss of *Berberis crataegina* DC. anthocyanin was determined as 33.607%, 36.399%, and 56.765% at 70, 80, and 90 °C, respectively. When considering their anthocyanin content during mild heat treatment (40 and 60 °C), *Berberis crataegina* DC. may be developed as a potential natural colorant for the pharmaceutical and food industries.

References

- Akbulut, M., Çalışır, S., Marakoğlu, T., & Çoklar, H. (2009). Some physicochemical and nutritional properties of barberry (*Berberis vulgaris* L.) fruits. *Journal of Food Process Engineering*, 32(4), 497-511. <http://dx.doi.org/10.1111/j.1745-4530.2007.00229.x>.
- Arici, M., Karasu, S., Baslar, M., Tokar, O. S., Sagdic, O., & Karaagacli, M. (2016). Tulip petal as a novel natural food colorant source: Extraction optimization and stability studies. *Industrial Crops and Products*, 91, 215-222. <http://dx.doi.org/10.1016/j.indcrop.2016.07.003>.
- Baytop, T. (1963). *Medicinal and poisonous plants of Turkey*. Turkey: Istanbul University Publication.
- Bing, L., Haji Akber, A., & Abulimiti, Y. (2019). Optimization of ultrasound-assisted extraction of sheep abomasum protein concentrates by response surface methodology and evaluation of their properties. *Food Science and Technology*, 39, 85-92.
- Brouillard, R., Iacobucci, G., & Sweeny, J. (1982). Chemistry of anthocyanin pigments. 9. UV-visible spectrophotometric determination of the acidity constants of apigeninidin and three related 3-deoxyflavylium salts. *Journal of the American Chemical Society*, 104(26), 7585-7590. <http://dx.doi.org/10.1021/ja00390a033>.
- Castañeda-Ovando, A., de Lourdes Pacheco-Hernández, M., Páez-Hernández, M. E., Rodríguez, J. A., & Galán-Vidal, C. A. (2009). Chemical studies of anthocyanins: A review. *Food Chemistry*, 113(4), 859-871. <http://dx.doi.org/10.1016/j.foodchem.2008.09.001>.
- Celli, G. B., Ghanem, A., & Brooks, M. S.-L. (2015). Optimization of ultrasound-assisted extraction of anthocyanins from haskap berries (*Lonicera caerulea* L.) using Response Surface Methodology. *Ultrasonics Sonochemistry*, 27, 449-455. <http://dx.doi.org/10.1016/j.ultsonch.2015.06.014>. PMID:26186866.
- Charehsaz, M., Sipahi, H., Celep, E., Üstündağ, A., Cemiloğlu Ülker, Ö., Duydu, Y., Aydın, A., & Yesilada, E. (2015). The fruit extract of *Berberis crataegina* DC: exerts potent antioxidant activity and protects DNA integrity. *Daru: Journal of Faculty of Pharmacy, Tehran University of Medical Sciences*, 23(1), 24. <http://dx.doi.org/10.1186/s40199-015-0108-7>. PMID:25884392.
- Chemat, F., Rombaut, N., Sicaire, A.-G., Meullemiestre, A., Fabiano-Tixier, A.-S., & Abert-Vian, M. (2017). Ultrasound assisted extraction of food and natural products. Mechanisms, techniques, combinations, protocols and applications. A review. *Ultrasonics Sonochemistry*, 34, 540-560. <http://dx.doi.org/10.1016/j.ultsonch.2016.06.035>. PMID:27773280.
- Chen, F., Sun, Y., Zhao, G., Liao, X., Hu, X., Wu, J., & Wang, Z. (2007). Optimization of ultrasound-assisted extraction of anthocyanins in red raspberries and identification of anthocyanins in extract using high-performance liquid chromatography-mass spectrometry. *Ultrasonics Sonochemistry*, 14, 767-778. <http://dx.doi.org/10.1016/j.ultsonch.2006.12.011>.
- Ding, Y., Zheng, J., Xia, X., Ren, T., & Kan, J. (2016). Box-Behnken design for the optimization of nanoscale retrograded starch formation by high-power ultrasonication. *Lebensmittel-Wissenschaft + Technologie*, 67, 206-213. <http://dx.doi.org/10.1016/j.lwt.2015.11.022>.
- Dranca, F., & Oroian, M. (2016). Optimization of ultrasound-assisted extraction of total monomeric anthocyanin (TMA) and total phenolic content (TPC) from eggplant (*Solanum melongena* L.) peel. *Ultrasonics Sonochemistry*, 31, 637-646. <http://dx.doi.org/10.1016/j.ultsonch.2015.11.008>. PMID:26701808.
- Eroğlu, A. Y., Çakır, Ö., Sağdıç, M., & Dertli, E. (2020). Bioactive characteristics of wild berberis vulgaris and berberis crataegina fruits. *Journal of Chemistry*, 2, 1-9.
- Fernandez-Barbero, G., Pinedo, C., Espada-Bellido, E., Ferreiro-González, M., Carrera, C., Palma, M., & Garcia-Barroso, C. (2019). Optimization of ultrasound-assisted extraction of bioactive compounds from jaboticaba (*Myrciaria cauliflora*) fruit through a Box-Behnken experimental design. *Food Science and Technology (Campinas)*, 39(4), 1018-1029. <http://dx.doi.org/10.1590/fst.16918>.
- Fuleki, T., & Francis, F. (1968). Quantitative methods for anthocyanins. 1. Extraction and determination of total anthocyanin in cranberries. *Journal of Food Science*, 33(1), 72-77. <http://dx.doi.org/10.1111/j.1365-2621.1968.tb00887.x>.
- Garzon, G., & Wrolstad, R. (2002). Comparison of the stability of pelargonidin-based anthocyanins in strawberry juice and concentrate. *Journal of Food Science*, 67(4), 1288-1299. <http://dx.doi.org/10.1111/j.1365-2621.2002.tb10277.x>.
- Gazeran, S., Tajalli, F., & Mohamadi Sani, A. (2016). Effect of ultrasonic extraction on qualitative parameters of saffron edible extract. *Journal of Essential Oil Bearing Plants*, 19(5), 1286-1291. <http://dx.doi.org/10.1080/0972060X.2015.1004126>.
- Ghafoor, K., Choi, Y. H., Jeon, J. Y., & Jo, I. H. (2009). Optimization of ultrasound-assisted extraction of phenolic compounds, antioxidants, and anthocyanins from grape (*Vitis vinifera*) seeds. *Journal of Agricultural and Food Chemistry*, 57(11), 4988-4994. <http://dx.doi.org/10.1021/jf9001439>. PMID:19405527.
- Gulsoy, S., Ozkan, G., & Ozkan, K. (2011). Mineral Elements, Phenolics and Organic Acids of Leaves and Fruits from *Berberis crataegina* DC. *Asian Journal of Chemistry*, 23(7), 3071.
- İşıklı, N. D., & Yılmaz, İ. (2014). Some physical properties of sun-dried *Berberis* fruit (*Berberis crataegina*). *Journal of Food Science and Technology*, 51(1), 104-110. <http://dx.doi.org/10.1007/s13197-011-0469-y>. PMID:24426054.
- Kara, Ş., & Erçelebi, E. A. (2013). Thermal degradation kinetics of anthocyanins and visual colour of Urmu mulberry (*Morus nigra* L.). *Journal of Food Engineering*, 116(2), 541-547. <http://dx.doi.org/10.1016/j.jfoodeng.2012.12.030>.
- Karasu, S., Bayram, Y., Ozkan, K., & Sagdic, O. (2019). Extraction optimization crocin pigments of saffron (*Crocus sativus*) using response surface methodology and determination stability of crocin microcapsules. *Journal of Food Measurement and Characterization*, 13(2), 1515-1523. <http://dx.doi.org/10.1007/s11694-019-00067-x>.
- Kirca, A., Ozkan, M., & Cemeroglu, B. (2003). Thermal stability of black carrot anthocyanins in blond orange juice. *Journal of Food Quality*, 26(5), 361-366. <http://dx.doi.org/10.1111/j.1745-4557.2003.tb00252.x>.

- Li, H.-Z., Tan, Y.-L., Zhang, Z.-J., Xia, Y.-Y., Li, X.-J., Cui, L.-X., & Chen, T., & Li (2019). Optimization of ultrasound-assisted extraction of procyanidins from perilla seed hull and their antioxidant activities in vitro. *Food Science and Technology (Campinas)*, 39(2), 378-387. <http://dx.doi.org/10.1590/fst.30417>.
- Martins, N., Roriz, C. L., Morales, P., Barros, L., & Ferreira, I. C. F. R. (2016). Food colorants: Challenges, opportunities and current desires of agro-industries to ensure consumer expectations and regulatory practices. *Trends in Food Science & Technology*, 52, 1-15. <http://dx.doi.org/10.1016/j.tifs.2016.03.009>.
- Mazza, K. E. L., Santiago, M. C. P. A., Nascimento, L. S. M., Godoy, R. L. O., Souza, E. F., Brígida, A. I. S., Borguini, R. G., & Tonon, R. V. (2019). Syrah grape skin valorisation using ultrasound-assisted extraction: Phenolic compounds recovery, antioxidant capacity and phenolic profile. *International Journal of Food Science & Technology*, 54(3), 641-650. <http://dx.doi.org/10.1111/ijfs.13883>.
- Motalleb, G., Hanachi, P., & Kua, S. (2005). Evaluation of phenolic content and total antioxidant activity in *Berberis vulgaris* fruit extract. *Journal of Biological Sciences*, 5(5), 648-653.
- Okafor, S., Obonga, W., & Ezeokonkwo, M. (2016). Assessment of the Health implications of Synthetic and Natural Food Colourants – A Critical Review. *UK Journal of Pharmaceutical Biosciences*, 4(4), 1. <http://dx.doi.org/10.20510/ukjpb/4/i4/110639>.
- Patras, A., Brunton, N. P., O'Donnell, C., & Tiwari, B. (2010). Effect of thermal processing on anthocyanin stability in foods; mechanisms and kinetics of degradation. *Trends in Food Science & Technology*, 21(1), 3-11. <http://dx.doi.org/10.1016/j.tifs.2009.07.004>.
- Ramić, M., Vidović, S., Zeković, Z., Vladić, J., Cvejic, A., & Pavlić, B. (2015). Modeling and optimization of ultrasound-assisted extraction of polyphenolic compounds from *Aronia melanocarpa* by-products from filter-tea factory. *Ultrasonics Sonochemistry*, 23, 360-368. <http://dx.doi.org/10.1016/j.ultsonch.2014.10.002>. PMID:25454824.
- Riciputi, Y., Diaz-de-Cerio, E., Akyol, H., Capanoglu, E., Cerretani, L., Caboni, M. F., & Verardo, V. (2018). Establishment of ultrasound-assisted extraction of phenolic compounds from industrial potato by-products using response surface methodology. *Food Chemistry*, 269, 258-263. <http://dx.doi.org/10.1016/j.foodchem.2018.06.154>. PMID:30100433.
- Rodrigues, S., Fernandes, F. A., Brito, E. S., Sousa, A. D., & Narain, N. (2015). Ultrasound extraction of phenolics and anthocyanins from jaboticaba peel. *Industrial Crops and Products*, 69, 400-407. <http://dx.doi.org/10.1016/j.indcrop.2015.02.059>.
- Sharifi, A., & Hassani, B. (2012). Extraction methods and stability of color extracted from barberry pigments. *International Journal of Agriscience*, 2(4), 320-327.
- Singleton, V. L., & Rossi, J. A. (1965). Colorimetry of total phenolics with phosphomolybdic-phosphotungstic acid reagents. *American Journal of Enology and Viticulture*, 16(3), 144-158.
- Siow, Y. L., Sarna, L. O. K., & O, K. (2011). Redox regulation in health and disease — Therapeutic potential of berberine. *Food Research International*, 44(8), 2409-2417. <http://dx.doi.org/10.1016/j.foodres.2010.12.038>.
- Skrypnik, L., & Novikova, A. (2020). Response Surface Modeling and Optimization of Polyphenols Extraction from Apple Pomace Based on Nonionic Emulsifiers. *Agronomy (Basel)*, 10(1), 92. <http://dx.doi.org/10.3390/agronomy10010092>.
- Toma, M., Vinatoru, M., Paniwnyk, L., & Mason, T. J. (2001). Investigation of the effects of ultrasound on vegetal tissues during solvent extraction. *Ultrasonics Sonochemistry*, 8(2), 137-142. [http://dx.doi.org/10.1016/S1350-4177\(00\)00033-X](http://dx.doi.org/10.1016/S1350-4177(00)00033-X). PMID:11326609.
- Ullah, N., Khan, S., Khan, A., Ahmad, W., Shah, Y., Ahmad, L., & Ullah, I. (2015). A prospective pharmacological review of medicinal herbs, *Cucumis melo* and *Berberis vulgaris*, commonly used in the treatment of renal diseases in Pakistan. *Acta Poloniae Pharmaceutica*, 72(4), 651-654. PMID:26647620.
- Wang, W.-D., & Xu, S.-Y. (2007). Degradation kinetics of anthocyanins in blackberry juice and concentrate. *Journal of Food Engineering*, 82(3), 271-275. <http://dx.doi.org/10.1016/j.jfoodeng.2007.01.018>.
- Yang, L., Cao, Y. L., Jiang, J. G., Lin, Q. S., Chen, J., & Zhu, L. (2010). Response surface optimization of ultrasound-assisted flavonoids extraction from the flower of *Citrus aurantium* L. var. *amara* Engl. *Journal of Separation Science*, 33(9), 1349-1355. <http://dx.doi.org/10.1002/jssc.200900776>. PMID:20309902.
- Yang, Z., Han, Y., Gu, Z., Fan, G., & Chen, Z. (2008). Thermal degradation kinetics of aqueous anthocyanins and visual color of purple corn (*Zea mays* L.) cob. *Innovative Food Science & Emerging Technologies*, 9(3), 341-347. <http://dx.doi.org/10.1016/j.ifset.2007.09.001>.
- Yeşilada, E., & Küpeli, E. (2002). *Berberis crataegina* DC. root exhibits potent anti-inflammatory, analgesic and febrifuge effects in mice and rats. *Journal of Ethnopharmacology*, 79(2), 237-248. [http://dx.doi.org/10.1016/S0378-8741\(01\)00387-7](http://dx.doi.org/10.1016/S0378-8741(01)00387-7). PMID:11801387.