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Antioxidant activity and phenolic composition of sumac (*Rhus coriaria* L.) extracts

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Abstract

Antioxidant activity and phenolic compounds of sumac extracts were investigated. Sumac was extracted in methanol and subjected to solvent–solvent partitioning to yield two fractions as ethyl acetate and aqueous. Methanol extract was further fractioned over Sephadex LH-20 column. Antioxidant activity of extracts and fractions were screened using ferric thiocyanate and DPPH radical scavenging methods. Phenolic composition of active fraction(s) was determined by HPLC–MS systems. Those fractions which exhibited strong antioxidant activity were rich in anthocyanins and hydrolysable tannins. While gallic acid was the main phenolic acid in the extracts, anthocyanin fraction contained cyanidin, peonidin, pelargonidin, petunidin, and delphinidin glucosides and coumarates. Pentagalloyl glucose was abundant in the hydrolysable tannin fraction. Effective scavenging concentration (EC_{50}) on DPPH radical was 0.70 μg/mL both in ethyl acetate and tannin fractions, and 5.33 μg/mL in anthocyanin rich fraction. Same extracts and fractions showed moderate lipid peroxidation inhibition effect compared with the synthetic antioxidants. The findings demonstrate that sumac can be used as a natural antioxidant.

Keywords: *Rhus coriaria*; Sumac; Antioxidant activity; Free radicals; HPLC; HPLC–MS; Lipid peroxidation

1. Introduction

Phenolic compounds, which are secondary metabolites in plant materials are known to be responsible for antioxidant effect. Recent epidemiological studies have strongly suggested that consumption of certain plant materials may reduce the risk of chronic diseases related to oxidative stress on account of their antioxidant activity and promote general health benefits (Halliwell, 1997). On the other hand, in the food industry, antioxidants are used to retard the oxidative degradation of fats by inhibiting the formation of free radicals. Synthetic antioxidants, such as butylated hydroxyanisole (BHA), butylated hydroxytoluene (BHT) and propylgallate (PG) are widely used; however, the use of synthetic antioxidants in food products is being questioned (Branen, 1975; Takajashi & Hiraga, 1978). Consumers have also become more cautious about the nutritional quality and safety of food additives. In response to the growing consumer demand, investigations on antioxidants from natural sources have gained interest (Pokorny, 1991). Fruits and vegetables are the main sources of phenolic compounds in human diet. Other sources, such as grains, herbs and spices, also have received particular attention as sources of antioxidants (Hannum, 2004; Nakatani, 2000).

The Mediterranean diet is particularly rich in spices. Sumac is one example, which is widely used in Turkey and the Middle East. The fruits are red colored and contain one seed. Its dried and ground leaves have been used as a tanning agent due to their high tannin content. Previous phytochemical studies of this plant reported that its leaves contained flavones, tannins, anthocyanins, and organic acids (Mavlyanov, Islambekov, Ismailov, & Kamaev,

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1995; Mavlyanov, Islambekov, Karimdzhanov, & Ismailov, 1997). However, it is the fruit of the plant that is typically consumed as spice after drying and grinding. Other reports indicated that sumac has antimicrobial activity with limited information on its antioxidant activity and potential as a new source of antioxidative substances, but these claims were not fully substantiated (Candan, 2003; Candan & Sokmen, 2004; Ozcan & Akgül, 1995; Zalacain, Alonso, Prodanov, & Carmona, 2000; Zalacain, Carmona, Lorenzo, Blazquez, & Alonso, 2002).

Although several studies reported the phenolics content of sumac, the literature lacks information on its antioxidant activity. Therefore, the objectives of this study were to investigate the antioxidant activity of sumac and to establish the relationship between the chemical composition and antioxidant activity of sumac extracts.

2. Materials and methods

2.1. Materials

Dried and ground sumac (*Rhus coriaria* L., Anacardiaceae) fruits were purchased from a local market in Eskisehir, Turkey. It was stored at −18 °C before use. Sephadex LH-20 was purchased from Pharmacia LKB Biotec. (Uppsala, Sweden). Standard phenolic compounds were purchased from Sigma–Aldrich Canada Ltd. (Oakville, ON, Canada).

2.2. Preparation of phenolic extracts and fractions

The experimental protocol used in the extraction and fractionation of sumac phenolics is shown in Fig. 1.

2.2.1. Extraction of crude phenolics

Plant material (10 g) was extracted with petroleum ether using a Soxhlet apparatus for 8 h. After drying, defatted plant material (3 g) was extracted with 40 mL of 70% (v/v) aqueous methanol in a shaker bath set at 40 °C for 30 min and filtered. This extraction step was repeated three times using the same batch of starting material. The filtrates were combined and methanol was evaporated at 40 °C using a rotavapor until dryness (extract 1). The solid residue was dissolved in 75 mL of water and extracted with 75 mL ethyl acetate three times. The ethyl acetate phases were combined and evaporated under vacuum at 40 °C using a rotavapor until dryness (extract 2). The aqueous phase remaining after ethyl acetate extraction was lyophylized (Virtis Co., Inc., Gardiner, NY) (extract 3). Yields of extracted matter were calculated as percentage (w/w) on defatted plant material.

2.2.2. Fractionation of phenolics

The fractionation of phenolics was carried out according to the methods of Wang and Lee (1996) and Strumeyer and Malin (1975) after slight modification (Fig. 1). For column chromatography (30 cm × 3 cm), Sephadex LH-20 gels were allowed to swell in 95% ethanol overnight. The methanolic extract (2 g) dissolved in 5 mL of 95% ethanol was applied to the column. The column was eluted sequentially with 99% ethanol, methanol and 50% aqueous acetone at a flow rate of 1.5 mL/min and 3.0 mL fractions were collected into 70 fractions of 3.0 mL each were collected. The absorbance of each fraction was determined at 280, 360, 520 nm using a diode array spectrophotometer (Hewlett Packard 8452A, Mississauga, ON, Canada), to decide when to switch the eluents and those fractions with similar absorbance values were combined (Fractions A–J). Fractions A–D, E–H, I–J were eluted with ethanol, methanol and 50% acetone, respectively (Fig. 2).

2.2.3. Hydrolysis of phenolics

Defatted plant material (5 g) was mixed with 150 mL of 1.2 M HCl in 50% (v/v) aqueous methanol for 1 h in a shaker water bath (Lab-Line Shaker Bath 3540, IL) at 80 °C. The extract was cooled, filtered and methanol was evaporated. The aqueous phase was extracted with 75 mL of ethyl acetate three times. Ethyl acetate phases were combined and evaporated under vacuum using a rotavapor at 40 °C until dryness (extract 4) (Justesen, Knuthsen, & Leth, 1998).

2.3. Compositional analyses

2.3.1. Total phenolics

Total phenolics content of sumac fractions was determined according to the Folin–Ciocaltaeu procedure (Gamez-Meza et al., 1999). All samples and gallic acid were dissolved in 50% (v/v) aqueous methanol. Samples (0.5 mL) were placed into test tubes and then 2.5 mL Folin–Ciocaltaeu reagent (10%, v/v, in water) solution and 7.5 mL sodium carbonate (20%, w/v, in water) solution were added. The tube contents were mixed and allowed to stand for 2 h at room temperature. Absorbance was measured at 750 nm and the total phenolic content was expressed as gallic acid equivalents (GAE) in mg per g dry material.

2.3.2. Total anthocyanins

Total anthocyanins were estimated by a pH differential method (Prior et al., 1998) using a diode array spectrophotometer. Absorbance was measured at 510 nm and 700 nm in buffers at pH 1.0 and 4.5 using a molar extinction coefficient of 29,600. Results were expressed as mg cyanidin-3-glucoside equivalent per g dry extract (Eq. (1)).

$$A = (A_{510} - A_{700})_{\mathrm{pH1.0}} - (A_{510} - A_{700})_{\mathrm{pH4.5}} \quad (1)$$

2.3.3. Tannins assays

The presence of the condensed and hydrolysable tannins within the extracts and fractions of sumac was determined using vanillin (Price, Van Scoyoc, & Butler, 1978) and gelatin (Okuda, 1999) assays, respectively. For the condensed tannins, 1 mL of methanolic sample solution was mixed

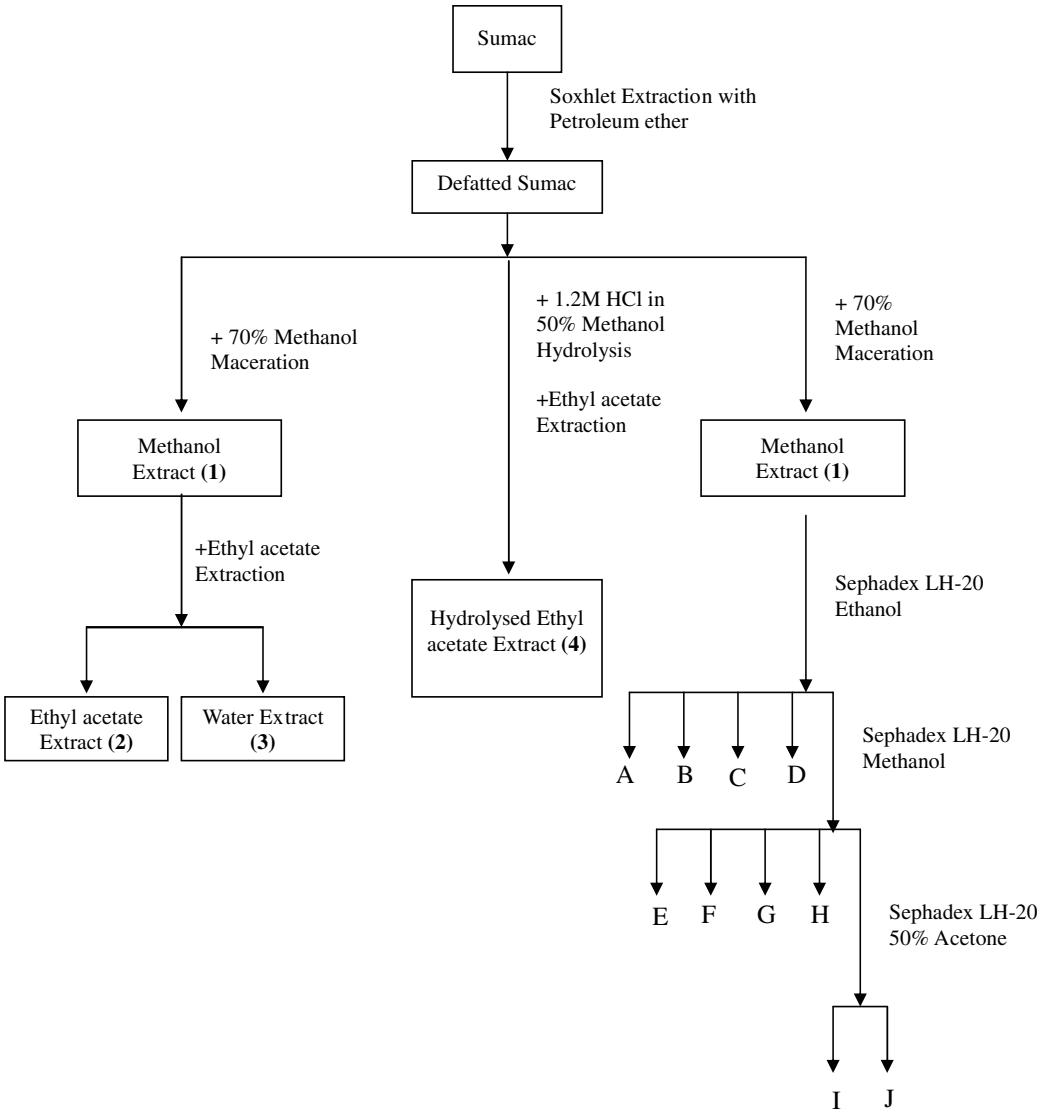

Fig. 1. The extraction and fractionation scheme of fruits of sumac fruits.

with 5 mL vanillin solution (0.5%) containing 4% of concentrated hydrochloric acid. After incubation at 30 °C for 20 min, the absorbance of reaction mixture was measured at 500 nm. The same solution without vanillin was used as a blank. Catechin was the positive control in this assay. For the hydrolysable tannins, 2 mL of gelatin solution was added into 5 mL of aqueous methanolic (50%) sample solution. The consecutive occurrence of precipitation in the reaction mixture shows the presence of hydrolysable tannins.

2.3.4. HPLC analysis of phenolic acids

Aliquots of extracts (25 μL) were analyzed using a HPLC system (Waters 2690 Alliance series, Mississauga, ON, Canada) equipped with a UV–VIS detector (Waters 486 Tunable Absorbance Detector) and an autosampler (Hewlett Packard 1050), operated by Shimadzu VP software. A reverse-phase C18 Ultrasphere column (250 × 4.6 mm; particle size 5 μm) was used. Solvent A, methanol:water:glacial acetic acid (10:88:2, v/v/v); and solvent B, methanol:water:glacial acetic acid (90:8:2, v/v/v) were used as the mobile phase for the analysis of phenolic acids. Linear gradients from 0% to 15% B in 15 min, from 15% to 50% B in 5 min, from 50% to 70% B in 9 min, and from 70% to 100% B in 6 min were applied, followed by a return to the initial conditions in 5 min and re-equilibration of the column (Rodriguez-Delgado, Malovana, Perez, Borges, & Garcia Montelonga, 2001). The standard solutions of phenolic acids, e.g. vanillic, gallic, protocatechuic and *p*-hydroxybenzoic acid were prepared at 1 mg/mL in methanol:water (50:50) and they were diluted to make five concentrations (2–40 μg/mL). Extracts were dissolved in methanol:water (50:50) and filtered through a nylon membrane filter (0.45 μm) before injection. Phenolic acids were identified by their retention times at 280 nm and quantified by using an external calibration curve.

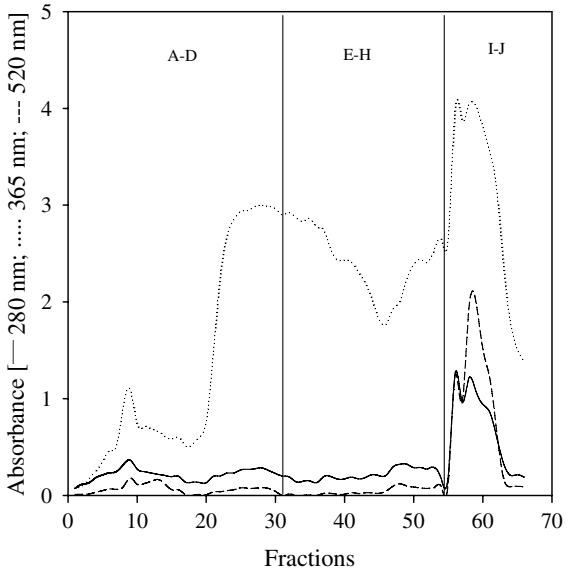

Fig. 2. Collection and combination of the fractions of sumac using their UV absorbances.

2.3.5. HPLC–MS analysis of phenolic compounds

Samples were analyzed using a HPLC system (Agilent Tech. 1100, Mississauga, ON, Canada), equipped with UV and MS detectors. The mass spectrometer was operated in both the negative-ion mode (3500 V) and positive-ion mode (4500 V). Samples were separated on a reverse-phase C18 Luna (Phenomenex, 150 × 2 mm; particle size 5 μm, Torrence, CA) column using 0.25 mL/min flow rate. Solvent A, 0.5% formic acid in water; and solvent B, 0.5% formic acid in methanol were used as the mobile phase for the analysis of phenolic acids. Linear gradients from 15% to 30% B in 15 min, from 30% to 50% B in 5 min and hold at 50% B for 5 min and increase from 50% to 80% B in 5 min, and from 80% to 90% B in 5 min were applied, followed by a return to the initial conditions in 5 min and re-equilibration of the column. Samples were dried with drying gas applied at 10 L/min flow rate and 350 °C temperature. Nebulising pressure of 25 psig was used in the mass spectrometer.

2.4. Determination of antioxidant activity

All extracts (1–4) and fractions (A–J) obtained as described above and (1–4, A–J) and commercial antioxidant (BHT, TBQH, α-tocopherol) were tested for their antioxidant activity using the following methods:

2.4.1. Free radical scavenging activity on DPPH

Free radical scavenging activity of the sumac fractions on 1,1-diphenyl-2-picrylhydrazyl (DPPH·) was estimated according to the method of Sanchez-Moreno, Larrauri, and Saura-Calixto (1998). The methanolic solution of sample extracts or commercial standards (0.5 mL) at the concentration of 4×10^{-3} mg/mL in reaction assay was added to 3 mL of DPPH· (0.02 g/L in methanol). The mixture was shaken vigorously and left standing at room temperature for 30 min; the absorbance of the resulting solution was then measured spectrophotometrically at 515 nm. The following calibration curve (Eq. (2), $R^2 = 0.9999$) obtained with DPPH· at the concentration range of 1.08×10^{-3} to 2.16×10^{-2} g/L was used to calculate the DPPH· concentration (g/L) in the reaction medium:

$$A_{515\text{nm}} = 26.15(\text{DPPH}^{\cdot})_t + 9.4 \times 10^{-3} \quad (2)$$

where $(\text{DPPH}^{\cdot})_t$ is the DPPH· concentration in the mixture at 30 min. The percentage of the remaining DPPH·(% $\text{DPPH}^{\cdot}_{\text{rem}}$) was calculated as follows (Eq. (3)):

$$\%\ \text{DPPH}^{\cdot}_{\text{rem}} = (\text{DPPH}^{\cdot})_{t=30}/(\text{DPPH}^{\cdot})_{t=0} \times 100 \quad (3)$$

The percentage of remaining DPPH· was plotted against the sample concentration to obtain the amount of sumac extract or antioxidant necessary to decrease the initial DPPH· concentration by 50% (IC_{50}).

2.4.2. Ferric-thiocyanate method

The protocol described previously (Jitoe et al., 1992; Osawa & Namiki, 1981) was used with small modifications. Extracts or commercial standards (0.5 mg/mL) in 4 mL of 99.5% (v/v) ethanol, 4 mL of 2.53% linoleic acid in 99.5% ethanol, 8 mL of 0.05 M phosphate buffer (pH 7.0), and 4 mL of distilled water was put in a glass bottle with a screw cap and placed in an oven (Fisher Scientific Canada, Ottawa, ON, Canada) at 40 °C in the dark for 30 days. Samples were drawn two times a week. To 0.1 mL of this sample a solution of 9.7 mL of 75% (v/v) ethanol and 0.1 mL of 30% (w/v) ammonium thiocyanate were added. Precisely 3 min after the addition of 0.1 mL of 0.02 M ferrous chloride in 3.5% hydrochloric acid to the reaction mixture, the absorbance of the mixture with red color developed was measured at 500 nm using a spectrophotometer.

2.5. Statistical analysis

Determination of total phenolics and total anthocyanins of each fraction was carried out in triplicate experiments. All statistical analyses were carried out using SPSS 10.0 for Windows® statistical software package. Analysis of variance was performed by ANOVA procedures. Significant differences between means were determined by Tukey's pairwise comparison test at a level of $p < 0.05$.

3. Results and discussion

3.1. Extraction and fractionation of phenolic compounds of sumac

The extraction yield obtained with methanol (70%) of defatted sumac was 29.77%. Total phenolic content of the methanol extract was 171.69 mg/g extract as gallic acid equivalent. Percentages (%) of ethyl acetate and water soluble fraction of total methanolic extract were 26.80% and 73.20%, respectively. Although ethyl acetate soluble

fraction of total extract was lower compared to that of water fraction, total phenolic content (540.65 mg GAE/g extract) was almost 100 times higher than that of water fraction (5.15 mg GAE/g extract). Almost all phenolic compounds were extracted with ethyl acetate from total methanolic extract. To obtain phenolics as aglycone structure, defatted sumac sample was extracted with 50% methanol containing 1.2 M HCl. After removal of methanol, the remaining aliquot phase was partitioned with ethyl acetate. The yield of ethyl acetate soluble matter of hydrolysed extract was 8.07%.

The methanol extract, was fractionated using a Sephadex LH-20 column, which was eluted with 95% ethanol followed by methanol. The residual substances remained on top of the column in methanol but could be eluted with 50% aqueous acetone. Ten fractions obtained from this column (Figs. 1 and 2) represented a total recovery of 75% of the material applied to the column according to their UV absorbances. These 10 fractions were used for compositional analysis and antioxidant activity tests. Of the total extract, 75% was eluted. Relative percentage (%) of fractions and their total phenolic content are shown in Table 1. Although the relative content of fractions A–C was as high as 24.82%, they contained no phenolic compound. Highest amount (30.76% of total eluent) was obtained in Fraction D, containing 142.9 mg total phenolic followed by Fraction I (20.58% of total eluent) with 346.7 mg total phenolic content as gallic acid equivalent per gram extract. Total phenolic content was highest in Fraction J (546.8 mg GAE/g); however, its relative amount was low at 4.39% than those of other fractions. Higher phenolic content of the last two fractions, comprising 63% of the total phenolic content of total eluents may indicate that higher molecular weight polyphenols were collected with 50% acetone as mobile phase. The red colored fraction (D) was richest in anthocyanins (Table 1).

3.2. Antioxidant activity of extracts and fractions

Two methods have been used to measure the antioxidant activity of sumac extracts and fractions: DPPH free radical scavenging activity and inhibition of linoleic acid peroxidation by the ferric thiocyanate method.

Table 1
Relative percentages and total phenolic content of fractions of sumac fractions

Fractions	Relative % of fractions	Total phenolic content (mgGAE/g extract)[a]	Total anthocyanins[a] ($mg_{Cy\text{-}3\text{-}gl}/g_{extract}$)
A	2.92	5.0 ± 1.9	
B	12.45	nd	
C	9.45	nd	
D	30.76	142.9 ± 2.4	2.30 ± 0.11
E	3.29	46.2 ± 4.3	0.30 ± 0.04
F	5.42	85.9 ± 1.6	0.21 ± 0.01
G	6.11	76.3 ± 7.9	0.20 ± 0.02
H	4.61	183.9 ± 3.0	
I	20.58	346.7 ± 2.1	
J	4.39	546.8 ± 4.6	

nd: Not detected.
[a] Results are expressed as means ± standard deviation ($n = 3$).

The DPPH$^{\cdot}$ free radical method determined the antiradical power of antioxidants (Sanchez-Moreno et al., 1998). Regarding the IC_{50} values, all the sumac fractions and the commercial standards (BHT: S1; TBHQ: S2 and α-tocopherol: S3) tested depleted the initial DPPH$^{\cdot}$ concentration by 50% within 30 min. The lower the IC_{50} value the higher the free radical scavenging activity of a sample indicating that a smaller amount is sufficient to decrease the concentration of DPPH$^{\cdot}$ by 50%.

The free radical scavenging activities of the fractions tested in this study are shown in Fig. 3. All extracts and fractions possessed strong radical scavenging activity at 30 μg/mL. The antioxidant activity of all samples was in the order: TBHQ = Extract 2 = J > I > Extract 4 > α-toc > H > Extract 1 = D > F > G > BHT = A. Extract 2 (0.72 μg/mL) and fraction J (0.71 μg/mL), which had the highest levels of total phenolics, had the highest ($p \leqslant 0.05$) free radical scavenging activity (or lowest IC_{50} value) similar to TBHQ (S2) ($p > 0.05$). Next were extract 4 (2.48 μg/mL) and fraction I, which had significantly ($p \leqslant 0.05$) lower IC_{50} compared to tocopherol at the same sample concentration. Extract 1, fractions D, F, G and H all performed significantly ($p \leqslant 0.05$) better than BHT (S1). A good correlation was found between the total phenolic content and free radical scavenging activity ($r^2 = 0.878$).

The effect of sumac fractions on the prevention of linoleic acid peroxidation was investigated by ferric-thiocyanate method. As seen in Fig. 4, extract 4 was more effective than α-tocopherol and similar to BHT in lipid peroxidation assay. Despite the fact that fractions D, F, H, I, and J were also effective in preventing lipid peroxidation, but they were not as good as BHT. Extracts 2,4 and fractions I, J were found to be the most active samples in this assay with a performance similar to or better than that of α-tocopherol (Figs. 4 and 5).

3.3. HPLC and HPLC–MS analyses of fractions

Four phenolic acids were present in the sumac extracts as determined by HPLC analysis and the results were shown in Table 2. Gallic acid was the main component in the extracts. In addition, protocatechuic acid, *p*-OH-benzoic acid and vanillic acid were also found in the extracts.

Since fraction D was rich in anthocyanins and fractions I and J possessed the highest DPPH scavenging activity, they were analyzed by HPLC–MS to identify their composition. In this investigation, the analytical methods used were mainly based on HPLC with UV/VIS detection and peak identification was carried out using the molecular weight and structural information obtained from HPLC–MS analysis with positive ionization at different fragmentation voltages, in addition to the data of the UV/VIS spectra. According to these results, fraction D was found to contain seven anthocyanins and two gallic acid derivatives.

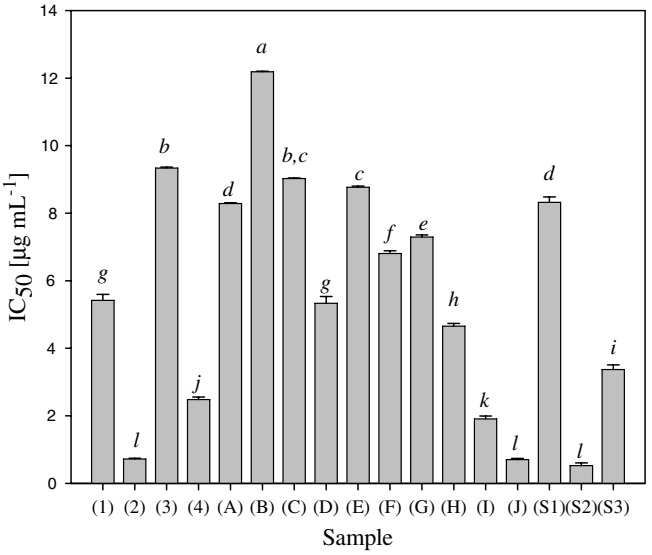

Fig. 3. DPPH· radical scavenging activity of extracts and fractions of sumac. Values are presented as mean values ± 95% confidence interval. Bars with the same letter (a–l) are not significantly ($p < 0.05$) different. 1–4, extracts; A–J, fractions; S1, BHT; S2, TBHQ; S3, α-tocopherol (see Fig. 1).

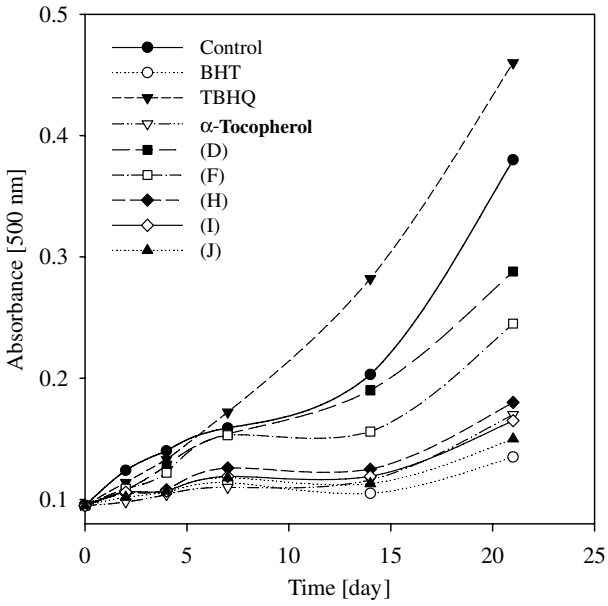

Fig. 5. Lipid peroxidation activity measured by ferric-thiocyanate method of sumac fractions (A–J).

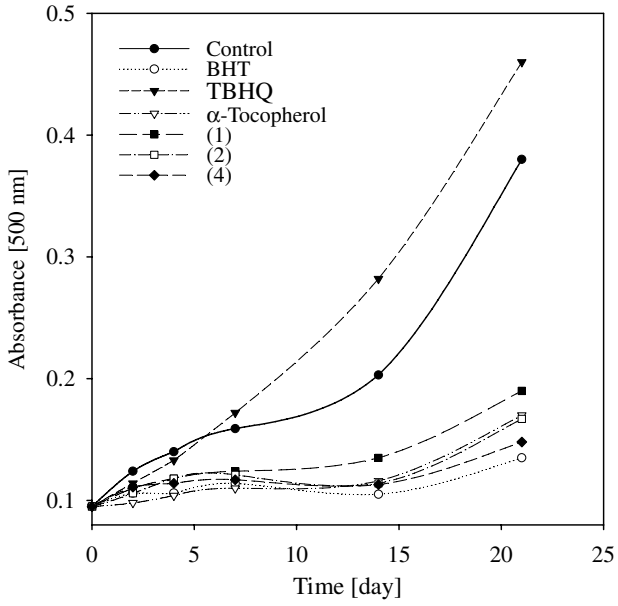

Fig. 4. Lipid peroxidation activity measured by ferric-thiocyanate method of sumac extracts (1–4).

After positive-mode analysis, cyanidin (M^+ 287), peonidin (M^+ 301), pelargonidin (M^+ 303), and petunidin (M^+ 319) structures and glucose/galactose (M^+ 162) and coumarate (M^+ 146) fragments were identified in fraction D. According to their fragmentations, anthocyanins in D were peonidin-3-glucoside (*m/z* 301, 463), petunidin-3-glucoside coumarate (*m/z* 319, 481, 627), petunidin-3-glucoside (*m/z* 319, 481), delphinidin-3-glucoside coumarate (*m/z* 303, 465, 611), delphinidin-3-glucoside (M^+ 303, 465), delphinidin coumaroyl glucoside (*m/z* 303, 449, 611), and cyanidin coumaroyl glucoside (*m/z* 287, 433, 595). Digallic acid (*m/z* 153, 171, 313) and galloyl coumarate (*m/z* 152, 323, 340, 467) were also identified in the same fraction.

There are only a few studies reporting the composition of anthocyanins in sumac fruit. For example, Mavlyanov et al. (1997) isolated cyanidin-3-β-D-glucoside, delphinidin-3-β-glucoside and delphinidin from the fruits of sumac. However, in this study cyanidin-glucoside was not found in fraction D among the anthocyanins identified.

The composition of fractions I and J were found to be similar. Gelatin assay was carried out on these two fractions and the results showed the presence of tannins in I and J. On the other hand, the same fractions did not give a positive response with vanillin assay, demonstrating the presence of condensed tannins. Fractions I and J were analyzed by HPLC–MS using negative-ion mode and gallate (M^+ 152) fragments were identified in these fractions. Therefore, hydrolysable tannins and gallic acid derivatives were decided to be present in I and J. Gallic acid methyl ester (*m/z* 183, 218, 297, 367), digallic acid methyl ester (*m/z* 153, 337) and pentagalloyl glucose (*m/z* 469, 939) were identified and pentagalloyl glucose was found to be the main compound in both fractions.

The main tannin compounds present in the *Rhus* family are hydrolysable gallotannins. Its basic structural unit is the polyol-D-glucose, esterified by gallic acid at its hydroxyl groups to give the β-pentagalloyl-D-glucose (Niemetz & Gross, 1998, 2001; Zalacain, Prodanov, Carmona, & Alonso, 2003). The presence of pentagalloyl glucose and gallic acid derivative tannins (gallotannins) in sumac leaves was reported previously (Niemetz & Gross, 1998, 2001). The use of a photodiode array detector with HPLC facilitates the discrimination between hydrolysable and

Table 2
Phenolic acid contents[a] of the extracts/fractions of sumac extracts/fractions

Sample	Gallic acid	Protocatechuic acid	*p*-OH-benzoic acid	Vanillic acid	Total
(1)	1.52 ± 0.10	0.04 ± 0.01	0.09 ± 0.00	0.05 ± 0.00	1.70 ± 0.02
(2)	4.14 ± 0.22	0.41 ± 0.02	0.81 ± 0.01	0.19 ± 0.01	5.55 ± 0.11
(4)	4.13 ± 0.18	0.27 ± 0 02	0.59 ± 0.01		4.99 ± 0.13
(D)	4.77 ± 0.20	0.21 ± 0.01	0.48 ± 0.02		5.46 ± 0.19
(E)	0.15 ± 0.03	0.08 ± 0.00	0.35 ± 0.01		0.58 ± 0.05
(F)	0.12 ± 0.01				0.12 ± 0.03

[a] Results (g/100 g extract) are expressed as means ± standard deviation ($n = 3$).

condensed tannins as their maximum wavelength is 280 and 360 nm, respectively.

There are some reports on the antioxidant activity of sumac. Both leaves and fruits were studied for their antioxidant activities. Tannin fractions of these samples were found to have a strong antioxidant activity (Zalacain et al., 2000; Zalacain et al., 2002). Candan and Sokmen (2004) reported the hydroxyl radical scavenging activities and lipid peroxidation activity of methanol extracts of sumac fruits. The IC_{50} value of the extract for lipid peroxidation in the Fe^{2+}–ascorbate system and hydroxyl radical scavenging activity in the deoxyribose decomposition method was reported as 1200 μg/mL and 282.92 μg/mL, respectively.

In this study, sumac extracts (ethyl acetate and hydrolysed) and fractions (D, I and J) showed remarkable antioxidant activity against inhibition of lipid peroxidation and scavenging activity on DPPH radical. Compositional data of active fractions (D, I and J) showed that these fractions contained anthocyanin and hydrolysable tannin derivatives. IC_{50} values of fractions I and J were comparable with those of purified monomeric hydrolysable tannins (Hatano et al., 1989; Yokozawa et al., 1998). For example, Hatano et al. (1989) reported that IC_{50} value of scavenging effect on DPPH radical for penta-*O*-galloyl-β-D-glucose was 0.66 μM. These studies clearly indicated that an increases in the number of hydroxyl groups resulted in an increase in the scavenging effect on the DPPH radical. Thus, our findings prompted us to think that the hydrolysable tannins may be responsible for the antioxidant activity of sumac. However, since no compositional analysis of these extracts was performed, further study is required to characterize all phenolics in the active extracts.

Acknowledgements

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