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Bioactive and antioxidant characteristics of blackberry cultivars from East Anatolia

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Abstract: Blackberry is commonly used both in the fresh and the processing market. In the present study antioxidant capacity, organic acids, phenolic compounds, vitamin C, and sugars content of blackberry cultivars grown in the east of Turkey were determined. Phenolic compounds, organic acids, vitamin C, and sugars were determined by HPLC. Antioxidant capacity was determined by spectrophotometric methods. The cultivar Cherokee had the highest antioxidant capacity (48.900 μmol TE g^{-1}), and the cultivar Jumbo had the lowest antioxidant capacity (30.855 μmol TE g^{-1}). It was determined that the chief phenolic compounds in blackberry cultivars were catechin (ranging from 111.599 to 438.970 mg 100 g^{-1}), followed by ellagic acid (ranging from 10.610 to 51.506 mg 100 g^{-1}). Looking at the content of organic acids, citric acid and malic acid came to the fore, ranging from 3.182 to 7.131 g kg^{-1} and 1.349 to 2.881 g kg^{-1}, respectively. Fructose content of the studied cultivars was higher than the glucose and sucrose contents. Results indicate that blackberry cultivars with higher antioxidant capacity and biochemical content may be valuable for nutritional breeding efforts.

Key words: Antioxidant, chemical diversity, phenolic compounds, organic acids

1. Introduction

Horticulture is concerned with plants that are used by people for food (edible products and culinary ingredients) as well as medicinal or ornamental and aesthetic purposes. Plants are genetically very diverse and play a major role in modern society and the economy. Fruits and vegetables are an important component of traditional foods, but are also central to healthy diets of modern urban populations (Bajpai et al., 2014; Feng et al., 2014; Ruttanaprasert et al., 2014; Mlcek et al., 2015).

Continuous increases in world population and changing climatic conditions may negatively impact diet, but they may also increase preferences for alternative products. Fruit production has considerable potential in this regard. Blackberry (*Rubus fruticosus* L.), a member of the family Rosaceae, provides delicious fruits that can be consumed fresh or as an ingredient in processed products such as ice cream, jam, jelly, marmalade, purées, fruit juices, liquors, and dietary supplements. In addition, the leaves and roots have been used for medicinal applications (Byamukama et al., 2005). Berry species are among the preferred fruit species for both human health and nutrition and for the food processing industry. There are 12 subgenera, and the subgenera *Eabatus* and *Idaebatus* and their species are important among them (Kurt et al., 2003). There is increasing interest in blackberry production due to its benefits for human health (it is a rich source of vitamins, minerals, and antioxidants) and its potential uses in the processing industry (Oruç, 2013). The first studies of blackberry cultivars started in the 18th century, thornless blackberries were found in the 1930s, and in recent years high-quality cultivars of blackberries adapted to different regions have been developed (Crandall, 1995; Moore and Skirvin, 1990).

Organic acids in fruits are effective in several physiological processes (taste formation, maturation, and so on) and are of great importance in human health (Cemeroğlu and Acar, 1986; Savran, 1999). The ratio of organic acids and sugars reveals the ripening status of the fruit. When acids are present at a lower rate, the fruit becomes sweet; in the case of a higher acid rate, the fruit has a sour property. Organic acids found in fruits produce no negative effect on the metabolism because they are oxidized very rapidly. The salts are important in the diet since they have an alkali impact (Schobinger, 1988; Savran, 1999). Organic acids block the effects of heavy metal ions on catalyzing oxidation by constructing complexes with them (Savran, 1999). The proportion of total acid content to sugar content in fruits is a criterion of maturity. Moreover, the type and amount of acidity in foods is a measure of deterioration. If the fruit molds during storage, an increase in some of the organic acids is observed.

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Organic acids can also have a significant effect on the control of purity (Özkaya, 1988; Savran, 1999; Gundogdu et al., 2011; Gundogdu and Yilmaz, 2012).

In studies conducted in recent years, it has been determined that some flavonoids have anticarcinogenic effects; therefore, the demand for fruits containing anthocyanins and anthocyanidins is increasing (Tosun and Artık, 1998). Plant foods have gained attention for human health and nutrition because studies have shown that they might reduce heart disease and cancer and the effects of aging. It is believed that plant nutrients have antioxidant characteristics that are capable of inhibiting free radicals that contribute to aging and some diseases (Pantelidis et al., 2007; Voca et al., 2008). Despite their low content in fruits and vegetables, phenolic compounds contribute to many problems in product processing (particularly the juice industry). They affect the taste of products and generate a sourish taste. Anthocyanin, one of the phenolic compounds, provides particular colors to the fruits and vegetables. Additionally, the catalyzing effects of polyphenol oxidase (PPO) enzymes cause a browning reaction in fruits and vegetables. Phenolic compounds also result in blurring and sedimentation in drinks such as fruit juices and wines. Phenolic compounds are present in almost all fruits and vegetables in varying amounts. Enzymatic browning does not occur in intact plant cells since phenolic compounds in cell vacuoles are separated from the PPO enzyme in the cytoplasm. Once tissue is damaged by slicing, cutting, or pulping, brown pigments are generated due to the reaction of phenolic compounds and the PPO enzyme. For example, some fruits and vegetables such as apple, banana, and potato turn brown immediately after slicing (Cemeroğlu and Yemincioğlu, 2004; Gundogdu et al., 2011).

Studies have demonstrated the important role of blackberry fruits in human health and nutrition. Accordingly, blackberry fruits are becoming more popular and their consumption has been increasing. The blackberry cultivars used in this study are commonly grown in Turkey. The study aimed to determine antioxidant capacity, phenolic compounds, organic acids, vitamin C, and sugars content of 11 blackberry cultivars grown in the Malatya region of Turkey. These parameters are important for quality determination in blackberry fruits. The study is important for exploring antioxidant capacity, phenolic compounds, and other chemical contents in blackberry cultivars for which limited literature is available.

2. Materials and methods

Eleven standard and local cultivars of blackberry (Bartın, Cherokee, Bursa 1, Arapaho, Bursa 3, Jumbo, Bursa 2, Cheater Thornless, Çitil, Loch Ness, and Navaho) were used in the study. They were grown in the Malatya Fruit Research Institute National Apricot Genetics Resources Plot. The cultivars used in all experiments were fresh harvested blackberries. Fruits were harvested at full ripening stage. We formed random lots, each with 30 fruits. Homogeneous fruits samples were collected at the harvest time determined for the blackberry fruits grown in Malatya Province. Approximately 500 g of fruit samples from each cultivar were maintained at –80 °C before analysis.

2.1. Chemicals

In the present study, chemicals with analytical purity were used. Organic acid standards (citric acid, malic acid, succinic acid, fumaric acid, and oxalic acid), phenolic acid standards (gallic, catechin, caffeic, chlorogenic, *o*-coumaric, *p*-coumaric, ferulic, vanillic, quercetin, rutin, ellagic, and pyrocatechol), sugar standards (glucose, fructose, and sucrose), and vitamin C standards (L-ascorbic acid) were obtained from Sigma-Aldrich (St. Louis, MO, USA). The other chemicals were obtained from Merck (Darmstadt, Germany).

2.2. Extraction and determination of phenolic compounds

The phenolic compounds were determined using the HPLC separation method described by Rodriguez-Delgado et al. (2001). About 100 g of samples was fragmented, and 5 g from each sample was transferred to centrifuge tubes. The samples were mixed homogeneously and then diluted 1:1 with distilled water and centrifuged at 15,000 × *g* for 15 min. The supernatant was passed through a 0.45-µm membrane filter (Millipore Millex-HV Hydrophilic PVDF; Millipore, USA) and then injected into the HPLC system (gradient). The chromatographic separation in the Agilent 1100 series HPLC took place in a DAD detector (Agilent, USA) of 250 mm × 4.6 mm with a 4-µm ODS column (HiChrom, USA). The following solvents were used in water with a flow rate of 1 mL/min and 20 µL of injection volume for spectral measurements at 254 and 280 nm: as mobile phase, solvent A (methanol–acetic acid–water, 10:2:88) and solvent B (methanol–acetic acid–water, 90:2:8).

2.3. Extraction and determination of organic acids

For organic acid extraction, the method by Bevilacqua and Califano (1989) was modified. About 200 g of sample was fragmented, and 10 g from each sample was transferred to centrifuge tubes. Then 10 mL of 0.009 N H_2SO_4 was added to the samples, and the samples were homogenized with Heidolph Silent Crusher M (Heidolph, Germany). The samples were then mixed for 1 h with a shaker (Heidolph Unimax 1010, Germany) and centrifuged at 14,000 rpm for 15 min. The supernatant was passed through coarse filter paper, then twice through a 0.45-µm membrane filter (Millipore Millex-HV Hydrophilic PVDF; Millipore,

USA) and finally the SEP-PAK C18 cartridge. The concentration of organic acids was determined by HPLC using an Aminex column (HPX-87H, 300 mm × 7.8 mm; Bio-Rad, USA) fitted on an Agilent 1100 series HPLC G 1322 A (Agilent Technologies, Germany) (Bevilacqua and Califano, 1989). Organic acids were detected at 214 and 280 nm wavelengths. As the mobile phase, 0.009 N H_2SO_4 was passed through a 0.45-µm filter membrane.

2.4. Extraction and determination of sugars

The samples were prepared according to the method described by Melgarejo et al. (2000) with minor modifications. Briefly, the 10-g samples of fruit were centrifuged at 12,000 rpm for 2 min at 4 °C. The supernatant was then filtrated with SEP-PAK C18 cartridges and transferred into a vial and used for analysis. Analysis of sugars was performed by HPLC (isocratic program) with a µBondapak-NH_2 column and refractive index (RI) detector using 85% acetonitrile as a mobile phase. The calculation of concentrations was based on standards prepared in the laboratory.

2.5. Extraction and determination of total antioxidant activity

For the standard Trolox equivalent antioxidant capacity (TEAC) assay, TEAC extract was prepared: ABTS was dissolved in acetate buffer and prepared with potassium persulfate, as described by Rice-Evans et al. (1995) and Özgen et al. (2006). The mixture was diluted in an acidic medium of 20 mM sodium acetate buffer (pH 4.5) to an absorbance of 0.700 ± 0.01 at 734 nm for longer stability (Özgen et al., 2006). For the spectrophotometric assay, 3 mL of $ABTS^+$ solution and 20 µL of fruit extract were mixed and incubated for 10 min, and the absorbance was determined at 734 nm, 6 min after mixing.

2.6. Extraction and determination of ascorbic acid (vitamin C)

Ascorbic acid content was determined following the modified HPLC (isocratic program) (Agilent 1100 series HPLC G 1322 A; Agilent Technologies, Germany) analytical procedure outlined by Cemeroğlu (2007). The 5-g sample was transferred to a 50-mL volumetric flask including 10 mL of 6% (w/v) metaphosphoric acid (M6285, 33.5%; Sigma). The sample was then homogenized at 24,000 rpm for 15 s and centrifuged at 14,000 rpm for 10 min at 1 °C. Then 5 mL of the supernatant was filtered through 0.45-µm PTFE syringe filters (Phenomenex, UK) and placed in an amber-colored vial (AIM, Screw Vial, SV-15A). Quantification of ascorbic acid was made by an external standard method using an L-ascorbic acid standard (Sigma A5960). Samples were separated on a Luna C18 column (250 mm × 4.60 mm, 5 µm; Phenomenex, USA) at 25 °C by HPLC. The mobile phase was 25 mM KH_2PO_4 (adjusted to pH 2.2 with phosphoric acid) with a flow rate of 1 mL/min; L-ascorbic acid was detected at 254 nm.

2.7. Statistical analysis

Descriptive statistics were expressed as average and standard error, and 2-factor factorial analysis of variance was used for comparing cultivar averages in terms of examined parameters. Subsequent to variance analysis, Duncan's multiple range test was used to determine the different cultivars (Zar, 1999). A statistical significance level of 5% was applied in the calculations, which were executed with SPSS 13.

3. Results and discussion

3.1. Organic acid content

Organic acids are known to affect taste formation in particular and many physiological processes. Oxalic acid, citric acid, succinic acid, fumaric acid, and malic acid contents of blackberry fruits were examined in this study (Table 1). There were statistically significant differences among cultivars in terms of organic acid contents ($P < 0.05$). Cherokee had the highest citric acid content (7.131 g kg^{-1}), while Çitil had the lowest (3.182 g kg^{-1}) citric acid content. The highest malic acid content was measured in Çitil (2.881 g kg^{-1}) and the lowest malic acid content was determined in Cherokee (1.349 g kg^{-1}). Bursa 2 had the highest succinic acid content (2.021 g kg^{-1}), while Jumbo had the lowest (0.953 g kg^{-1}) succinic acid content. The highest fumaric acid content was measured in Cheater Thornless (0.155 g kg^{-1}), and the lowest fumaric acid content was determined in Cherokee (0.048 g kg^{-1}). Cherokee had the highest oxalic acid content (0.774 g kg^{-1}), while Bartın had the lowest (0.264 g kg^{-1}) oxalic acid content. Organic acids are water-soluble materials found in the cytoplasm of fruits and vegetables in various amounts. Accompanied by the sugars, they contribute to the taste of fruits and vegetables (Cemeroğlu et al., 2004). In the present study, there were significant differences among the fruit organic acid contents of blackberry cultivars (Table 1). As seen from these results, the most predominant organic acid in these blackberry cultivars was citric acid, generally followed by malic, succinic, oxalic, and fumaric acids. On the other hand, succinic acid content was higher than malic acid content in Cherokee and Bursa 1. Kafkas et al. (2006) reported that malic acid content and total acidity content of the five blackberry genotypes varied from 0.6 to 11.0 g kg^{-1} and from 1.3 to 25.9 g kg^{-1}, respectively. The same researchers identified the ascorbic acid in some genotypes, but were unable to identify it in other genotypes. Vrhovsek et al. (2008) studied the citric acid and malic acid content of blackberry genotypes in Italy and found a range from 1.1 to 16.7 g kg^{-1} and from 4.0 to 15.8 g kg^{-1}, respectively. The same researchers were unable to identify citric acid in some genotypes. The findings of the present study showed some correlation with the

Table 1. Organic acid contents in fruits of blackberry cultivars (g kg^{-1}).

Cultivars	Citric acid	Malic acid	Succinic acid	Fumaric acid	Oxalic acid
Bartın	3.781 ± 0.068 i*	1.636 ± 0.012 e	1.470 ± 0.014 d	0.063 ± 0.003 d	0.264 ± 0.014 d
Cherokee	7.131 ± 0.122 a	1.349 ± 0.038 g	1.523 ± 0.051 d	0.048 ± 0.001 f	0.774 ± 0.063 a
Bursa 1	6.846 ± 0.018 b	1.788 ± 0.011 d	1.946 ± 0.019 b	0.051 ± 0.001 ef	0.384 ± 0.048 c
Arapaho	4.933 ± 0.054 f	1.962 ± 0.037 c	1.834 ± 0.027 c	0.086 ± 0.003 b	0.547 ± 0.008 b
Bursa 3	6.172 ± 0.220 d	1.427 ± 0.016 fg	1.066 ± 0.012 g	0.057 ± 0.002 de	0.578 ± 0.021 b
Jumbo	4.548 ± 0.033 g	1.775 ± 0.031 d	0.953 ± 0.058 h	0.044 ± 0.004 f	0.554 ± 0.015 b
Bursa 2	6.377 ± 0.094 c	2.103 ± 0.027 b	2.021 ± 0.062 a	0.075 ± 0.002 c	0.752 ± 0.005 a
Cheater Thornless	3.940 ± 0.014 h	2.021 ± 0.024 bc	1.352 ± 0.033 e	0.155 ± 0.006 a	0.289 ± 0.012 d
Çitil	3.182 ± 0.051 j	2.881 ± 0.025 a	1.277 ± 0.019 f	0.075 ± 0.001 c	0.380 ± 0.011 c
Loch Ness	5.056 ± 0.038 e	1.490 ± 0.071 f	1.071 ± 0.012 g	0.066 ± 0.002 d	0.527 ± 0.028 b
Navaho	4.599 ± 0.059 g	1.609 ± 0.027 e	0.992 ± 0.010 h	0.080 ± 0.003 bc	0.378 ± 0.020 c

*: Significant differences ($P < 0.05$) among cultivars having different letters.

results of other researchers. During the processes of fruit harvesting, storage, and analysis, the loss in organic acids is reduced to a minimum, but the situation cannot be avoided completely. Consequently, reactions and changes in the physiology of fruits affect organic acid content. It is also thought that differences in the organic acidity content of the blackberry cultivars might have arisen from genetic factors, climatic factors, and/or cultural practices (Poyrazoğlu et al., 2002).

3.2. Sugar, Trolox equivalent antioxidant capacity, and vitamin C content

Sugars in fruits are among the main factors affecting the formation of taste. Differences in sugar content in the fruits of blackberry cultivars were statistically significant ($P < 0.05$). In the present study, the fructose, glucose, and sucrose contents of the studied blackberry cultivars ranged from 19.699 (Bursa 3) to 28.868 mg g^{-1} (Jumbo), from 9.139 (Bursa 3) to 15.381 mg g^{-1} (Jumbo), and from 1.217 (Çitil) to 4.019 mg g^{-1} (Jumbo), respectively (Table 2). Fructose content was higher than the content of other sugars and it was the predominant sugar in blackberry fruits. The cultivar Jumbo had the highest fructose, glucose, and sucrose contents; the cultivar Bursa 3 had the lowest fructose and glucose contents. The sucrose content was lower than the content of other sugars in the blackberry fruits. Kafkas et al. (2006) observed that the fructose, glucose, sucrose, and total sugar contents of the blackberry genotypes studied ranged from 21.1 to 33.8 g/kg, from 15.8 to 26.1 g kg^{-1}, from 1.2 to 2.6 g kg^{-1}, and from 38.2 to 62.5 g kg^{-1}, respectively. These findings parallel the findings of the present study. The differences in sugar contents of the blackberry genotypes may have arisen from genetic factors, climatic factors, and/or cultural practices (Özgen et al., 2008). Depending on the sugar content variation, differences in properties among the cultivars are thought to be caused by environmental factors. Vitamin C and TEAC contents of the cultivars ranged between 10.288 and 25.399 mg 100 g^{-1} and 3.855 and 48.900 μmol TE g^{-1}, respectively (Table 2). Vitamin C content was the highest in the cultivar Arapaho. Cherokee had the highest Trolox equivalent antioxidant capacity (TEAC), while Jumbo had the lowest TEAC. Statistically important differences were recorded among the vitamin C and TEAC contents of the cultivars ($P < 0.05$). Tamer (2012) determined that the ascorbic acid and antioxidant activity contents of blackberry were 7.60–18.11 mg 100 g^{-1} and 1.79%–12.11% (0.3 mg/mL, on a dry basis), respectively. Ochmian et al. (2009) observed vitamin C content of blackberry at 11 mg 100 g^{-1}. In a study on cultivars of blackberry, antioxidant activities were determined by spectrometric method, and FRAP values of blackberry were measured from 35.05 to 70.41 μmol g^{-1} (Koca and Karadeniz, 2009). Our findings in the present study are in line with the results of the above-mentioned researchers. Antioxidant activities differed among cultivars, as indicated in the literature (Scalzo et al., 2005).

3.3. Phenolic profile

There were statistically significant differences among cultivars in terms of phenolic content ($P < 0.05$). Phenolic compound contents in fruits of blackberry were determined by HPLC and 12 phenolic compounds were examined in the blackberry samples in the study. Gallic

Table 2. Total antioxidant capacity (TEAC), vitamin C, and sugars contents in fruits of blackberry cultivars.

Cultivars	Vitamin C (mg 100 g^{-1})	TEAC (µmol TE g^{-}1 fw)	Fructose (mg g^{-1})	Glucose (mg g^{-1})	Sucrose (mg g^{-1})
Bartın	15.455 ± 0.216 f*	31.880 ± 0.130 fg	20.547 ± 0.125 g	12.841 ± 0.470 cd	3.258 ± 0.170 c
Cherokee	23.490 ± 1.019 b	48.900 ± 0.270 a	26.423 ± 0.149 c	14.452 ± 0.731 ab	3.646 ± 0.332 abc
Bursa 1	14.744 ± 0.121 g	38.470 ± 0.408 d	20.676 ± 0.332 g	10.604 ± 0.400 fg	2.702 ± 0.061 d
Arapaho	25.399 ± 0.273 a	34.425 ± 1.205 e	25.439 ± 1.198 d	14.209 ± 0.342 b	3.209 ± 0.037 c
Bursa 3	20.775 ± 0.680 d	31.255 ± 0.685 g	19.699 ± 0.227 h	9.139 ± 0.132 h	2.056 ± 0.040 e
Jumbo	11.803 ± 0.161 h	30.855 ± 0.780 g	28.868 ± 1.108 a	15.381 ± 1.073 a	4.019 ± 0.033 a
Bursa 2	15.347 ± 0.169 f	32.725 ± 0.545 f	22.240 ± 0.821 f	10.199 ± 0.750 gh	2.634 ± 0.039 d
C. Thornless	12.221 ± 0.503 h	45.500 ± 0.340 b	23.574 ± 0.991 e	11.474 ± 0.472 ef	3.564 ± 0.093 bc
Çitil	22.564 ± 1.250 c	30.895 ± 0.175 g	20.500 ± 0.430 g	10.273 ± 0.270 gh	1.217 ± 0.057 f
Loch Ness	10.288 ± 0.855 i	40.537 ± 0.330 c	25.454 ± 0.780 d	12.118 ± 0.752 de	3.827 ± 0.036 ab
Navaho	16.119 ± 0.171 e	38.275 ± 0.255 d	28.289 ± 1.004 b	13.619 ± 0.345 bc	3.762 ± 0.025 ab

*: Significant differences (P < 0.05) among cultivars having different letters.

acid content ranged between 2.198 and 9.428 mg 100 g^{-1}, caffeic content between 1.159 and 12.897 mg 100 g^{-1}, *p*-coumaric acid content between 0.390 and 1.268 mg 100 g^{-1}, *o*-coumaric acid content between 0.018 and 0.064 mg 100 g^{-1}, ferulic acid content between 0.389 and 2.745 mg 100 g^{-1}, ellagic acid content between 10.610 and 51.506 mg 100 g^{-1}, catechin content between 111.599 and 438.970 mg 100 g^{-1}, rutin content between 0.972 and 11.834 mg 100 g^{-1}, quercetin content between 0.218 and 0.536 mg 100 g^{-1}, vanillic acid content between 0.269 and 1.459 mg 100 g^{-1}, protocatechuic acid content between 0.394 and 1.179 mg 100 g^{-1}, and chlorogenic acid content between 0.504 and 1.175 mg 100 g^{-1} (Tables 3 and 4). Catechin and ellagic acid were the predominant phenolic compounds in blackberry

Table 3. Phenolic compounds in fruits of blackberry cultivars (mg 100 g^{-1}).

Cultivars	Gallic acid	Caffeic acid	*p*-Coumaric acid	*o*-Coumaric acid	Ferulic acid	Ellagic acid
Bartın	2.198 ± 0.125 h*	1.159 ± 0.030 j	0.390 ± 0.008 h	0.018 ± 0.000 e	0.389 ± 0.007 i	25.358 ± 0.259 g
Cherokee	9.428 ± 0.600 a	12.897 ± 0.585 a	1.148 ± 0.040 b	0.059 ± 0.001 b	1.551 ± 0.025 c	51.506 ± 1.793 a
Bursa 1	5.962 ± 0.230 c	4.330 ± 0.027 g	0.829 ± 0.025 d	0.021 ± 0.001 e	1.442 ± 0.006 d	36.558 ± 0.428 d
Arapaho	6.212 ± 0.525 b	7.278 ± 0.320 c	0.951 ± 0.010 c	0.053 ± 0.002 c	1.452 ± 0.036 d	43.865 ± 0.676 c
Bursa 3	3.627 ± 0.644 f	6.170 ± 0.340 d	1.149 ± 0.040 b	0.051 ± 0.000 c	1.647 ± 0.013 b	28.128 ± 0.114 f
Jumbo	2.639 ± 0.112 g	4.342 ± 0.127 g	0.963 ± 0.012 c	0.064 ± 0.002 a	1.663 ± 0.009 b	33.319 ± 0.102 e
Bursa 2	4.758 ± 0.410 d	3.231 ± 0.098 h	0.845 ± 0.009 d	ND	1.187 ± 0.001 f	26.002 ± 0.416 g
Cheater Thornless	4.002 ± 0.258 e	5.599 ± 0.076 e	0.714 ± 0.001 e	0.043 ± 0.001 d	1.264 ± 0.010 e	48.482 ± 0.222 b
Çitil	5.840 ± 0.192 c	10.025 ± 0.380 b	1.268 ± 0.027 a	ND	2.745 ± 0.007 a	13.462 ± 0.065 h
Loch Ness	2.759 ± 0.066 g	1.858 ± 0.020 i	0.467 ± 0.025 g	ND	0.875 ± 0.007 g	10.610 ± 0.107 i
Navaho	3.899 ± 0.096 e	5.347 ± 0.106 f	0.575 ± 0.012 f	ND	0.774 ± 0.002 h	25.553 ± 0.343 g

*: Significant differences (P < 0.05) among cultivars having different letters. ND: None detected.

Table 4. Phenolic compounds in fruits of blackberry cultivars (continuation of Table 3) (mg 100 g^{-1}).

Cultivars	Catechin	Rutin	Quercetin	Vanillic acid	Protocatechuic acid	Chlorogenic acid
Bartın	438.970 ± 5.074 a*	2.537 ± 0.010 f	0.396 ± 0.005 c	0.916 ± 0.004 c	0.954 ± 0.026 b	0.684 ± 0.005 d
Cherokee	298.156 ± 9.790 c	5.223 ± 0.009 c	0.306 ± 0.003 f	1.459 ± 0.017 a	0.762 ± 0.012 c	0.953 ± 0.011 c
Bursa 1	176.029 ± 2.676 f	4.328 ± 0.021 d	0.333 ± 0.006 e	0.498 ± 0.011 h	0.544 ± 0.021 f	0.720 ± 0.061 d
Arapaho	134.017 ± 7.585 g	5.708 ± 0.048 b	0.367 ± 0.004 d	0.368 ± 0.004 i	0.616 ± 0.015 e	0.670 ± 0.022 d
Bursa 3	383.115 ± 6.537 b	1.793 ± 0.025 h	0.261 ± 0.004 g	0.791 ± 0.005 e	0.683 ± 0.072 d	1.175 ± 0.024 a
Jumbo	240.823 ± 4.256 d	2.051 ± 0.046 g	0.218 ± 0.001 h	0.829 ± 0.012 d	0.952 ± 0.014 b	1.048 ± 0.037 b
Bursa 2	199.748 ± 3.758 e	3.930 ± 0.006 e	0.226 ± 0.007 h	0.689 ± 0.006 f	0.565 ± 0.092 f	1.164 ± 0.069 a
Cheater Thornless	232.862 ± 2.444 d	11.834 ± 0.141 a	0.536 ± 0.003 a	0.625 ± 0.011 g	1.179 ± 0.087 a	0.674 ± 0.006 d
Çitil	111.599 ± 1.472 h	0.972 ± 0.010 j	0.426 ± 0.010 b	0.335 ± 0.012 i	0.713 ± 0.031 d	0.923 ± 0.032 c
Loch Ness	376.252 ± 2.815 b	1.371 ± 0.015 i	0.400 ± 0.002 c	1.254 ± 0.019 b	0.702 ± 0.017 d	0.504 ± 0.007 e
Navaho	195.994 ± 3.517 e	ND	0.426 ± 0.007 b	0.269 ± 0.007 j	0.394 ± 0.001 g	0.885 ± 0.014 c

*: Significant differences ($P < 0.05$) among cultivars having different letters. ND: None detected.

cultivars. In the study of Türkben et al. (2010), ellagic acid, ferulic acid, caffeic acid, and *p*-coumaric acid contents in the Aksu Kırmızısı blackberry cultivar (fresh fruits) were 1018.15 mg kg^{-1}, 683.18 mg kg^{-1}, 349.61 mg kg^{-1}, and 361.68 mg kg^{-1}, respectively. Sellappan et al. (2002) reported that the gallic acid, caffeic acid, *p*-coumaric acid, ferulic acid, ellagic acid, and catechin in fruits of the Choctaw cultivar were 6.42 mg 100 g^{-1}, 1.38 mg 100 g^{-1}, 2.08 mg 100 g^{-1}, 3.51 mg 100 g^{-1}, 33.81 mg 100 g^{-1}, and 312.86 mg 100 g^{-1}, respectively. The findings of the present study were in line with the literature. Similar findings were obtained in different studies of phenolic compound content of blackberry fruits (Siriwoharn et al., 2004; Mertz et al., 2007). Flavonol glycoside, which is one of the phenolic compounds, is light yellow in color and exists in almost all plants. As light is required for its synthesis in plants, it is more abundantly present in the skins of fruits. Since they affect color formation, climatic factors of temperature and light are particularly important determinants (Cemeroğlu et al., 2004). Additionally, phenolic compounds generate a sourish taste in fruit products and blurred appearance in fruit juices (Cemeroğlu et al., 2004). Hence, phenolic compounds are highly important in the fruit juice processing industry.

The sugar-to-acid ratio in fruit is considered one of the major factors that determines harvest criteria as a quality parameter (Shaw, 1988; Cordenunsi et al., 2002). In the present study, organic acid and sugar contents in the fruit of blackberry cultivars were determined. Concentrations of biochemical characteristics (phenolics, antioxidant capacity, organic acids, sugars, and vitamin C) are known to be strongly influenced by factors such as cultivar, genotype, and rootstock. Our data show that there are important differences among cultivars. The phenolic component was irregular among cultivars. The results of this study could be significant for determination of biochemical characteristics in blackberry cultivars and as a reference for forthcoming studies. There has been limited research on the biochemical contents of blackberry; therefore, the present study is important in this aspect. Moreover, concern with the maintenance of the studied cultivars and their importance for human health (antioxidant properties and nutrition) may increase the value of the present work.

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