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COMPARATIVE ANALYSIS OF ANTIOXIDANT ACTIVITY IN SOME FRUIT SPECIES

SUMMARY

The aim of this work is determination of antioxidant activity of fruits from several species: apple, cherry, pomegranate, strawberry, black currant, white mulberry, chokeberry, blackberry, depending on the content of vitamin C, total anthocyanins and phenols. The highest antioxidant activity, about 86%, is shown by the pomegranate and black currant fruits. Lower values compared to the average antioxidant activity are shown by apple, cherry and strawberry fruits. The highest content of vitamin C (216.0 mg/100g) and the relative contribution of vitamin C on calculated antioxidant activity (250.6) is found in black currant. The highest content of anthocyanins are found in chokeberry (610 mg/100g) and black currant (580.0 mg/100g). Apple fruits had the lowest content of vitamin C (9.4 mg/100g) and anthocyanins (0.7 mg/100g). The highest content of total phenols is found in chokeberry (2390.0 mg/100g) and black currant (1860.0 mg/100g) and the lowest in white mulberry (10.0 mg/100g). A large contribution of vitamin C in the antioxidant activity is found in black currant, strawberry and white mulberry. Anthocyanins contribute most to the antioxidant activity of chokeberry, blackcurrant, blackberry and cherry fruits, while total phenols in chokeberry, blackcurrant, blackberry, pomegranate and apple fruits. In terms of the parameters examined, statistically significant differences were determined between the examined species. A weak positive correlation was determined for total antioxidant activity with vitamin C (0.399) and moderate positive correlation with total anthocyanins (0.534) and phenols (0.556), which indicates that in the examined species, antioxidant activity depends more on the content of total anthocyanins and phenols.

Keywords: fruit species, vitamin C, anthocyanins, total phenols, antioxidant activity

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INTRODUCTION

Fruits are referred to as “functional foods” and have an important place in the human diet. Fresh fruits are irreplaceable, health-safe food rich in bioactive compounds such as vitamins, carotenoids, flavonoids, tannins, proteins, carbohydrates, vitamins, minerals, plant fibers and other phenolic constituents that have a structural, energetic and protective function in the human body. These compounds play a synergistic and cumulative role in promoting human health, they have potent antioxidant activity and exhibit several health-promoting properties, have anti-inflammatory, anti-hyperglycemic, hypo-cholesterolemic activities (Tulipani *et al.,* 2009; Vauzour *et al.,* 2010; Giampieri *et al.,* 2012; Miller *et al.,* 2019). The diversity of secondary metabolites, including flavonoids, carotenoids and terpenoids, contributes to the nutritional richness of fruits and their potential health-promoting effects (Manach *et al.,* 2004; Khoo *et al.*, 2017). Antioxidants, encompassing a diverse array of compounds such as vitamins C and E, polyphenols and carotenoids, have been widely acknowledged for their ability to counteract oxidative stress, a process implicated in the pathogenesis of chronic diseases including cardiovascular disorders and certain cancers (Halliwell and Gutteridge, 2015).

Polyphenols are among the most abundant groups of substances present in fruits, with about 8000 phenolic structures. Some of them contribute to the formation of the taste and color of fruits and vegetables, others play a protective role against predators and pests, still others perform specific physiological functions during plant development and for the most part their functions have not yet been clarified. Phenols are divided into two main groups, flavonoids and non-flavonoids. Flavonoids are the most abundant group of phyto-chemicals, they include flavones (luteolin and apigenin), flavonols (quercetin, kaempferol, and myricetin), flavonones (narigenin), isoflavonoids (daidzein and genistein), anthocyanidins (malvidin and cyanidin) and flavanols (epicatechin, catechin, epigallocatechin, epigallocatechin gallate, epicatechin gallate) (Danyo and Ivantsova, 2025). Anthocyanins are water-soluble pigments and are stored in plant cell vacuoles. Most vascular plant species contain these compounds in various quantities in most of the organs, but mainly fruits, flowers, and leaves (Horbowicz *et al,* 2008; Viskelis *et al.*, 2010).

Phenolic compounds are a common ingredient in various nutraceutical supplements due to their positive effects on human body. The presence of flavonoids reduces the degree of oxidation of LDL cholesterol and removes free radicals. Flavonoids have been shown to inhibit lipid peroxidation within the phospholipid bilayer by localization within the polar and nonpolar phases (Movileanu *et al.,* 2000). Anthocyanins have various biological functions, provide protection from UV radiation, have antioxidant activity, and protect against various pathogens. They neutralize enzymes that destroy connective tissue, their antioxidant capacity prevents oxidants from damaging connective tissue and they repair damaged proteins in the blood-vessel walls (Horbowicz *et al.,* 2008). Proanthocyanidins have antihistamine, antiviral, anti-inflammatory and anti-caries effects. They protect the body from cardiovascular diseases, have anticancer effects and protect against UV radiation (Fartzov *et al.,* 1994). Ascorbic acid plays an important role in many metabolic functions, it is an antioxidant that protects the body from the harmful effects of free radicals and is used as a therapeutic agent in many diseases and disorders, protects the immune system, reduces the intensity of allergic reactions and helps fight infections. The recommended daily amount of vitamin C can be achieved by consuming a handful of strawberries (Carr and Frei, 1999). According to Bailey and Gregory (1999) 200-250 grams of strawberries may provide sixty-two percent of the daily folic acid. Thanks to their high-water content and low-calorie content, fruits are recommended in weight loss diets and to combat obesity. The fiber and fructose content can help regulate blood sugar levels (Samia *et al.,* 2019).

The antioxidant power of fruit is closely correlated to the presence of efficient oxygen radical scavengers, such as vitamin C and phenolic compounds. Through comparative analyses of the antioxidant activity of fruits from several fruit species, recommendations can be made for individual species in the prevention or treatment of certain diseases.

MATERIAL AND METHODS

As a result of many years of work in examining the polyphenolic composition of fruits from some fruit species, in this paper are provided comparative values for the antioxidant activity of fruits from different fruit species: pomegranate (*Punica granatum* L), apple (*Malus domestica* (Suckow) Borkh), cherry (*Prunus avium* L.) and some berry fruits as strawberry (*Fragaria* x *anannasa* Duch.), black currant (*Ribes nigrum* L.), white mulberry (*Morus alba* L.), chokeberry (*Aronia melanocarpa* (Michx.) Elliott) and blackberry (*Rubus fruticosus* L.). 30 fruits were taken in three replicates from each fruit species. The fruits were grown under natural conditions and harvested at botanical maturity. They were stored in refrigerators under appropriate conditions, for a short time until the samples are analyzed. Part of the data was obtained within the framework of the project titled "Antioxidant activity of fruits from indigenous varieties and populations of fruits, vegetables and grapes”. Additionally, chokeberry, blackberry, blackcurrant and mulberry fruits were taken from local markets. There is no information about the method and conditions of cultivation for the commercially available fruits. They are taken from local markets and kept in cold storage.

The laboratory analyses were performed in the oenological laboratory at the Institute of Agriculture in Skopje. The fruits were taken at botanical maturity and the analyses were performed for each species individually according to the time of ripening.

Determination of vitamin C

The content of vitamin C (mg/100 g) was examined by volumetric method which involved titration with 2,6 dihloroprophenol indofenol. The filtrate is titrated to a pale pink color. Samples with a higher degree of red staining were treated with 50 mg of activated carbon before titration, until complete decolourization was achieved (Sadasivam and Balasubramanian, 1987).

Methods for determination of total phenols and anthocyanins

Sample preparation: Take approximately 5 g mass of the sample (the fruit) and let it macerate in a closed container with a solution of ethanol, water and hydrochloric acid in the ratio 70:30:0.1 for 24 h.

Determination of total phenols

Total phenols in the samples are determined according to the Folin-Ciocalteu method. 1 mL of the prepared sample is placed in a 10 mL flask. 5 mL of distilled water and 0.5 mL of Folin- Ciocalteu reagent are added (Slinkard and Singleton, 1977). After 3 minutes, 1.5 mL of 20% solution of Na2CO3 is added and the flask is fill up to the mark with distilled water. Then the flask are placed in a water bath heated to 50 ˚C for 16 minutes. Then they are cooled and total phenols are measured on a spectrophotometer at 765 nm wavelength. In parallel with the samples, a blank sample is prepared, where distilled water is used instead of the tested sample and the rest of the reagents remain the same.

Determination of total anthocyanins

The content of total anthocyanins was performed according to the acid - ethanol method (Somers and Evans, 1977) In a 10 mL flask, add 0.1 mL of the macerated sample and fill up to the mark with the solution of ethanol, water and hydrochloric acid. A solution of ethyl chloride is used as a blank sample. Determination of anthocyanins was carried out by spectrophotometer, at a wavelength of 550 nm.

The content of total phenols and anthocyanins was performed by Agilent 8453 UV-VIS spectrophotometer. These methods are significantly suitable for routine analyses. They are rapid and can be applied to monitor changes in phenols composition during fruit ripening.

Determining of the antioxidant activity was performed as an anti-radical activity against the stable product DPPH (2,2-diphenyl-1-picrylhydrazil). The determination was performed spectrophotometrically, at a wavelength of 517 nm. The antioxidant activity, especially for vitamin C, as well as the inhibitory antioxidant activity of all concentrations are expressed in percent (%).

Statistical analysis

To determine a significant difference from the mean values of the four parameters (vitamin C, antioxidant activity, total phenols and total anthocyanins), ANOVA and the Least Significant Difference (LSD) test at the $p<0.05$ level were used for all fruit species samples. The correlation between the examined fruit species, as well as for all examined concentrations, was determined through correlation coefficient (r.) description (LaMorte, 2021) (Table 1).

Table 1. Correlation coefficient (r.) description (LaMorte, 2021)

Correlation coefficient	*Description*
+1.0	Perfect positive
+0.8 to 1.0	Very strong positive
+0.6 to 0.8	Strong positive
+0.4 to 0.6	Moderate positive
+0.2 to 0.4	Weak positive
0.0 to +0.2	Very weak positive or no association
0.0 to -0.2	Very weak negative or no association
-0.2 to – 0.4	Weak negative
-0.4 to -0.6	Moderate negative
-0.6 to -0.8	Strong negative
-0.8 to -1.0	Very strong negative
-1.0	Perfect negative

RESULTS AND DISCUSSION

The values for antioxidant activity and the content of the most important antioxidants in the fruits of some species are presented in Table 2.

The relative contribution of vitamin C or anthocyanins (expressed in mg/100g) contained in the obtained percentage of antioxidant activity inhibition was calculated as the contribution of vitamin C and anthocyanins in 100%inhibition antioxidant activity. Regarding the examined parameters, it was determined statistically significant differences between the fruit species (Table 3). The very high relative contribution of vitamin C on calculated antioxidant activity in blackcurrant (250.6), in contrast to other examined fruit species (24.4-54.3), is primarily due to the high content of vitamin C (216.0 mg/100g), which is also confirmed by literature data (Moyer *et al.,* 2002). The apple has the lowest vitamin C content (9.4 mg/100g) and the lowest contribution of vitamin C on calculated antioxidant activity (15.6) (Table 2).

The results correspond with available literature data. Several fruits accumulate high amounts of vitamin C at their optimal ripening, especially citrus fruits like grapefruits 40 mg/100 g, orange 41.3-62.7 mg/100 g (Dhuique-Mayer *et al.,* 2005), lemon 26.69-29.91 mg/100 g (Di Matteo *et al.,* 2021), strawberries 56.8-108.1 mg/100 g (Kim *et al.,* 2015; Boonyakiat *et al.*, 2016), kiwi 22.2-93.5 mg/100g (Nishiyama *et al.,* 2004), but other fruits accumulate significantly less ascorbic acid as for example in apple 2–10 mg/100 g, cherry 8 mg/100 g (Davey *et al.,* 2000), pear 4.4-10.2 mg/100g (Abaci *et al.*, 2016), apple (M.pumila) 0.05-0.96 mg% (Li *et al.,* 2021).

Compared to other berry fruits (Koca *et al.,* 2008; Selamovska *et al.,* 2024), pomegranate varieties (Selamovska *et al.*, 2022a), cherry varieties (Selamovska *et al.*, 2022b) and apple varieties (Selamovska *et al.,* 2022c), strawberry fruits have a higher content of ascorbic acid. Black currant has a higher content of ascorbic acid than strawberries (Hagg *et al.*, 1995; Paunović *et al.,* 2017).

Table 2. Content of vitamin C (mg/100g), total anthocyanins (mg/100g FW), total phenols (mg/100g FW) and antioxidant activity (%inhibition) in some fruit species

Fruit species	Antioxidant activity (% inhibition)	Vitamin C (mg/100g)	Relative contribution of vit. C in calculated antioxidant activity	Anthocyanins (mg/100g)	Relative contribution of anthocyanins in calculated antioxidant activity	Total phenols (mg/100g)
Apple	60.4	9.4	15.6	0.7	1.2	438.3
Cherry	43.4	12.8	29.6	39.4	90.8	138.6
Pomegranate	86.3	25.0	28.9	50.0	57.9	590.0
Strawberry	50.4	54.3	107.7	3.6	7.1	256.6
Black currant	86.2	216.0*	250.6*	580.0	672.8	1860.0
White mulberry	71.6	29.9	41.7	10.0	14.0	10.0
Chokeberry	76.4	24.2	31.7	610.0*	798.4*	2390.0*
Blackberry	78.6	19.2	24.4	170.0	216.3	760.0
Average	**69.2**	**48.8**	**66.3**	**182.9**	**232.3**	**805.4**

**The highest value for the parameter*

The very high content of anthocyanins in chokeberry (610.0 mg/100g) and black currant (580 mg/100g) indicates that anthocyanins have the largest contribution in the total antioxidant activity of the fruits in these species. The lowest content of anthocyanins (0.7 mg/100g) and the lowest relative contribution of anthocyanins on calculated antioxidant activity (1.2) have apple fruits. According to the statistical analysis, it was determined that there is a large variation and statistically significant differences in the content of anthocyanins between fruit species (Table 3). The results of our analyses correspond to the data from the available literature references.

The main dietary sources of anthocyanins are red fruits. Anthocyanins in fruits and vegetables are present in glycosylated forms. They are accumulated in cell vacuoles and they are largely responsible for diverse pigmentation from orange to red, purple and blue in flowers, fruits, such as: blackberry, red and black raspberries, blueberries, bilberries, cherries, currants, blood orange, elderberries, grapes and some vegetables (Horbowicz *et al.*, 2008). Total anthocyanin content in selected common fruits according to literature sources (Horbowicz *et al.*, 2008) is: apple (peel) 100 - 2160 mg/kg, bilberry 4600 mg/kg, blackberry 820 - 1800 mg/kg, blueberry 825 - 5300 mg/kg, cherry 3500 - 4500 mg/kg, chokeberry 5060 - 10000 mg/kg, cranberry 460 - 2000 mg/kg, orange 2000 mg/kg, plum 19 - 250 mg/kg, red raspberry 100 - 600 mg/kg, strawberry

127 - 360 mg/kg, black currant 1300 - 4000 mg/kg, red currant 119 - 186 mg/kg. *Ribes nigrum* and *Vaccinium corymbosum* accumulated slightly fewer anthocyanins up to 380 and 430 mg/100 g FW, respectively (Petruskevicius *et al.*, 2023). Black raspberry had the highest anthocyanin content, over 200 mg/100g of fruit, and red raspberry had the lowest, less than 60 mg/100g. Blackberry was generally intermediate in anthocyanin content between red and black raspberries (Torre and Barritt, 1977). In strawberry, total anthocyanin content ranged between 200 and 600 mg/kg (Lopes-da-Silva *et al.*, 2002). Brazilian blueberry varieties have relatively high concentration of total anthocyanins 140–318 mg/100g (Pertuzatti *et al.*, 2014).

In terms of the content of total phenols, a statistically significant difference was determined between the fruit species. The very high content of total phenols in chokeberry (2390 mg/100 g) and black currant (1860 mg/100 g) indicates that they have a large contribution in the total antioxidant activity of the fruits. The lowest content of total phenols is in white mulberry (10.0 mg/100 g). The low content of polyphenols is not consistent with the obtained results for antioxidant activity, which may be due to the different maturity of the fruits when taking a sample for analysis and performing the chemical analysis on a different day. The results of our analyses correspond to the data from the available literature references. The results of some autors (Proteggente *et al.*, 2002; Pellegrini *et al.*, 2003; Halvorsen *et al.*, 2006) have showed that berries are consistently ranked among the top sources of total phenols and TAC (total antioxidant capacity), with levels up to 4 times greater than other fruits, 10 times greater than vegetables and 40 times greater than cereals. According to Pertuzatti *et al.* (2014) Brazilian blueberry varieties have relatively high concentration of total phenols (1622–3457 mg gallic acid equivalents (GAE) per 100 g dry weight (DW). Wild fruits have the higher TPC value 226.3±1.14 mg GAE/g, than cultivated fruits (135.17±2.02 mg QE/g) (Phuyal *et al.*, 2020). The content of total phenolic in fruit peel of mango (*Mangifera indica*) is 503 mg gallic acid equivalents (GAE)/g and 228 mg gallic acid equivalents (GAE)/g in fruit peel of apple (*Malus domestica*) (Sadef *et al.*, 2022).

Table 3. One-way ANOVA results for differences among fruit species

Source of Variation	*Sum of squares (SS)*	*Degrees of freedom (df)*	*Mean square (MS)*	*F- statistic value*	*P-value*	*F-critical*
Between Groups	3349844	5	669968.9	4.359	0.003	2.438
Within Groups	6455183	42	153694.8			
Total	9805028	47				

The investigated fruit species showed high antioxidative activity, average 69.2%. Blackcurrant and pomegranate have the largest value, over 86%. Lower values compared to the average antioxidant activity are shown by apple, cherry and strawberry fruits. In general, berry fruits show high antioxidant activity, over 50%, compared to other fruit species. According to the statistical analysis, it was determined that there is a large variation between fruit species in terms of antioxidant activity, which indicates significant differences between species (Table 4).

Table 4. Descriptive statistics of antioxidant parameters across fruit species

Groups	Count	Sum	Average	Variance
Antioxidant activity (%inhibition)	8	553.3	69.1625	260.5541
Vitamin C (mg/100g)	8	390.83	48.85375	4748.177
Relative contribution of vit.C to calculated antioxidant activity	8	530.2	66.275	6364.931
Anthocyanins (mg/100g)	8	1463.7	182.9625	67680.51
Contribution of anthocyanins to calculated antioxidant activity	8	1858.5	232.3125	102425.7
Total phenols (mg/100g)	8	6443.5	805.4375	740689.1

The results from the analyses correspond to the data from the available literature references. According to several authors, the highest antioxidant activity was found in berry fruits.According to Wang *et al.* (1996), Scalzo *et al.* (2005), strawberry have a higher antioxidant capacity than apple, peach, pear, white grape, banana, plum, orange, pink grapefruit, kiwi. On the basis of the dry weight of fruit, strawberries had the highest oxygen radical absorbance capacity (ORAC), followed by black raspberries (cv. Jewel), blackberries and red raspberries (Wang and Lin, 2000). According to Zheng and Wang (2003) chokeberry have higher antioxidant activity compare to blueberry (*Vaccinium corymbosum*), cranberry (*Vaccinium macrocarpon*) and lingonberry (*Vaccinium vitis-idaea*). Purple mulberry has lower antioxidant activity than other berry fruits (*Rubus*, *Vaccinium* and *Ribes*) (Koca *et al*., 2008). In some cherry varieties of the species *Elaeagnus umbellate*, the antioxidant activity is 4.32-9.49 mM TE/100g (Lachowicz *et al*., 2019), in bird cherry (*Prunus padus*) is 7.26-31.54 mM/kg (Mikulic-Petkovsek *et al.*, 2016), in some apple and strawberry varieties the antioxidant activity is 12- 64 mM FRAP (Kaur and Kapoor, 2005). The percentage of inhibition in apple (*Malus domestica*) and mango (Man*gifera indica*), according to Sadef *et al.*, (2022) is 67.27% and 73.16%, respectively. Antioxidant activity in orange is 27.12%, in grapefruit is 56.91% (Siddhartha *et al.*, 2025). Prior *et al*., (1998) were the first authors to notice that blueberries have higher antioxidant activity by the ORAC method, confirming that, compared to other fruits and vegetables, blueberries have a relatively high antioxidant activity.

Given that the antioxidant capacity of fruits is attributed to the presence of phenolic compounds, ascorbic acid, tannins, in this paper we provide comparative values of these three parameters and their influence on antioxidant activity (Table 1). A large contribution of vitamin C in the antioxidant activity is found in black currant, strawberry and white mulberry fruits. Anthocyanins contribute most to the antioxidant activity of chokeberry, blackcurrant, blackberry and cherry fruits, while total phenols in chokeberry, blackcurrant, blackberry, pomegranate and apple fruits. A weak positive correlation of total antioxidant activity with vitamin C (0.399) and a moderate positive correlation with total anthocyanins (0.534) and total phenols (0.556) was found, indicating that in the studied fruit species, antioxidant activity depends more on the content of total anthocyanins and total phenols. (Table 5).

Table 5. Correlation between vitamin C, total anthocyanins and total phenols with antioxidant activity

	Antioxidant activity (%inhibition)	Vitamin C (mg/100g)	Relative contribution of vit C on calculated antioxidant activity	Anthocyanins (mg/100g)	Relative contribution of anthocyanins on calculated antioxidant activity	Total phenols (mg/100g)
Antioxidant activity (% inhibition)	1					
Vitamin C (mg/100g)	0.399	1				
Relative contribution of vit.C on calculated antioxidant activity	0.267	0.982	1			
Anthocyanins (mg/100g)	0.534	0.590	0.518	1		
Relative contribution of anthocyanins on calculated antioxidant activity	0.493	0.528	0.457	0.996	1	
Total phenols (mg/100g)	0.556	0.468	0.394	0.972	0.973	1

The result from our research aligns well with previous studies. In a study by Tulipani *et al.,* (2008), this individual contribution was investigated in different strawberry cultivars, where vitamin C was found to be one of the most important components, responsible for more than 30 % of the TAC (total antioxidant capacity) of strawberry extracts, followed by anthocyanins contributing 25 - 40 %; and the rest was composed mainly of EA derivatives and flavonols. The antioxidant activity attributed to strawberry is strongly related to the content of extractable polyphenols and vitamin C (Bezerra Almeida *et al.,* 2019). According to Heinonen *et al.,* (1998), Wang and Lin (2000) strawberry fruits (*Fragaria×ananassa* Duch.) have been shown to possess high in vitro antioxidant activity that has been positively correlated with the content of polyphenolic compounds, specifically, anthocyanins.

Citrus fruits have a high content of ascorbic acid. The content of this vitamin is considered a basic indicator of the quality and nutritional value of fruits and fruit products. Although ascorbic acid has lower antioxidant activity than phenolic compounds, including phenolic acids, tannins, catechins, and anthocyanins, its multifaceted antioxidant activity should be stressed (Rafiq *et al.,* 2018).

Several studies (Ovando *et al.,* 2009; Ćujić *et al.,* 2013) indicate a positive correlation between the content of anthocyanins in fruits and high antioxidant activity in some fruit species. About 70% of the total antioxidant capacity comes from anthocyanins (Lopes-da-Silva *et al.,* 2002; Giampieri *et al.,* 2012). Main factors of antioxidant activity in berry fruits are anthocyanins. Blackberries are known to contain a broad range of phenolic compounds and flavonoids, which contribute to their strong antioxidant capacity. Cranberries have big antioxidant punch, thanks to the anthocyanins and polyphenols. Blueberries are among the highest antioxidant-rich fruits, loaded with anthocyanins (Loliger, 1991).

According to Zheng and Wang (2003), Gazdik *et al.,* (2008) the chokeberry had significantly higher antioxidant activity related to the higher content of anthocyanins and phenolics. Prior *et al.,* (1998) investigated the antioxidant capacity of different Vaccinium species, emphasizing the role of specific antioxidants, such as anthocyanins, in determining the overall antioxidant potential. Red raspberries antioxidants are primarily from ellagic acid and anthocyanins.

Total phenols participate in the antioxidant activity in walnut (*Juglans regia* L.) (Oliveira *et al.,* 2008), pomegranate, cherry (Selamovska *et al.,* 2022a, b), apple fruits (Eberhardt *et al.,* 2000; Selamovska *et al.,* 2022c) purple mulberry (Koca *et al.,* 2008) and other berry fruits (Wang and Lin, 2000; Kahkonen *et al.,* 2001).

Flavanols (catechin and oligomeric procyanidins) are the major class of apple polyphenols, representing more than 80%, followed by hydroxycinnamic acids (1-31%), flavonols (2-10%), dihydrochalcones (0.5-5%), and in red apples, anthocyanins (1%) (Wojdylo *et al.,* 2008). The results of Pertuzatti *et al.,* (2014) show that Brazilian blueberries have a relatively high concentration of phenolic compounds and total anthocyanins, along with a small concentration of carotenoids. It was also shown that these compounds have a positive correlation with antioxidant activity.

In pecan nuts, ellagic acid, gallic acid, protocatechuic, p-hydroxybenzoic acids contribute most to the antioxidant activity (Do Prado *et al.,* 2009). Raspberries (*Rubus idaeus* L.) have high levels of vitamin C and phenolic compounds. Ellagic acid is of particular interest from a dietary view point as it has been reported to have antiviral and accounts for over 30% of the antioxidant activity of the fruit (Mullen *et al.,* 2003). Aaby *et al.,* (2005) determined that strawberry achenes contributed eleven percent of total phenolics and fourteen percent of the antioxidant activity. The authors found that ellagitannins and ellagic acid are the main contributors of antioxidant activity within strawberry achenes.

In addition to the genotype (species and variety) the amounts and types of bioactive compounds and their antioxidant activity are dependent on some factors: plant material (Wang and Lin, 2000; Do Thi and Hwang, 2014; Czech *et al.,* 2021), maturity stage (Kalt and McDonald, 1996; Pineli *et al.,* 2011; Minutti-López Sierra *et al.,* 2019), growing conditions (Wang and Zheng, 2001; Vagiri, 2018), time of harvest, cultivation systems (Wang and Millner, 2009; Melgarejo *et al.,* 2017; Bezerra Almeida *et al.,* 2019), storage period (Kalt *et al.,* 1999; Lee and Kader, 2000), industrial processing (Pellegrini *et al.,* 2003; Wolfe *et al.,* 2003; Aaby *et al.,* 2005).

Fruits and leaves of fruit species have great antioxidant activity. According to Czech *et al.,* (2021) whole lemons, limes, and especially mandarins also had higher antioxidant potentials than their pulps. Compared with fruits, leaves were found to have higher ORAC values. As the leaves become older, the ORAC values and total phenolic contents decreased (Wang and Lin, 2000). According to Do Thi and Hwang (2014) the chokeberry leaves contained a large proportion of the total phenolic and flavonoid contents of the chokeberry fruits. The young leaves contained more phenols and flavonoids than the old leaves, basal leaves and dormant buds have the highest content of total phenols.

Blackberries and strawberries have the highest ORAC values during the green stages, whereas red raspberries had the highest ORAC activity at the ripe stage (Pineli *et al.,* 2011; Minutti-López Sierra *et al.,* 2019). Monomeric anthocyanins, which accounted for greater than 85% of the total anthocyanin content in the samples of lowbush blueberry (*Vaccinium angustifolium* Aiton) were substantially higher in the ripe fruit than in underripe fruit and slightly higher compared to overripe berries (Kalt and McDonald, 1996).

Plants grown in the cool day and cool night temperature (18/12 °C) generally had the lowest phenolic acid, flavonols and anthocyanins. An increase in night temperature from 12 to 22 °C, with the day temperature kept constant at 25 °C, resulted in a significant increase in phenolic acid, flavonols and anthocyanins. These conditions also resulted in a significant increase in antioxidant capacity (Wang and Zheng, 2001). According to Vagiri (2018) blackcurrant cultivars grown in more northern and cooler regions have higher content of flavan-3-ols, phenols, flavonols and antioxidant activity compared to cultivars grown in southern and warmer regions.

The cultivation systems and cultivars influence on the antioxidant activity, physicochemical and sensory properties in fruits. Strawberry cultivated on the conventional system shows higher values for physicochemical variables and antioxidant activity, than strawberry cultivated on hydroponics in gutters and slabs (Bezerra Almeida *et al.,* 2019). Fruit from plants grown in compost socks had significantly higher oxygen radical absorbance capacity (ORAC), flavonoids, anthocyanins, sugars and acids than fruit produced in the black plastic mulch or matted row systems (Wang and Millner, 2009). The strawberries grown under dredged remediated sediment (DRS) and Peat-DRS substrate (mixture 50%) show a high content in vitamin C, total phenols and antioxidant activity, also have the highest sweetness index and a good firmness (Melgarejo *et al.,* 2017).

Kalt *et al.*, (1999) reported changes in phenolic composition, anthocyanin, and antioxidant capacities in Fresh strawberries (*Fragaria* x *ananassa* Duch.), raspberries (*Rubus idaeus* Michx.), highbush blueberries (*Vaccinium corymbosum* L.) and lowbush blueberries (*Vaccinium angustifolium* Aiton) during postharvest storage treatments. A study by Lee and Kader (2000) demonstrated that the vitamin C content of strawberries and kiwi fruits declined during storage, with variations attributed to oxygen levels. Thus, the packaging and storage conditions during and after processing emerge as critical factors influencing the nutritional outcomes of processed fruits.

Phenolic content and antioxidant activity of strawberry achenes were reduced by industrial processing (Aaby *et al.,* 2005). Processing methods, such as canning, freezing and drying, subject fruits to various environmental stresses, potentially influencing the stability and bioavailability of antioxidants. Pellegrini *et al.,* (2003) evaluated the impact of different processing methods on the total antioxidant capacity of various plant foods. Their findings highlighted variations in the antioxidant levels of processed fruits compared to their fresh counterparts, emphasizing the need for a nuanced approach in assessing the nutritional consequences of processing. According to Wolfe *et al.,* (2003) conventional heat treatments, such as pasteurization, led to a reduction in the antioxidant capacity of apple peels. The antioxidant activity of fruits is significant from a health perspective. A large contribution of vitamin C in the antioxidant activity is found in black currant, strawberry and white mulberry. Anthocyanins contribute most to the antioxidant activity of chokeberry, blackcurrant, blackberry and cherry fruits, while total phenols in chokeberry, blackcurrant, blackberry, pomegranate and apple fruits.

CONCLUSIONS

The highest value for antioxidant activity is found in pomegranate and black currant fruits. Apple, cherry and strawberry fruits show lower values compared to the average antioxidant activity.

The highest content of vitamin C (216.0 mg/100g) and the highest contribution of vitamin C in antioxidant activity (250.6) has black currant. The highest content of anthocyanins and the highest contribution of anthocyanins in antioxidant activity have chokeberry (610 mg/100g) and black currant (580.0 mg/100g). Apple fruits have the lowest content of vitamin C (9.4 mg/100g) and anthocyanins (0.7 mg/100g). The highest content of total phenols and antioxidant activity have chokeberry (2390.0 mg/100g) and black currant (1860.0 mg/100g).

Vitamin C has a significant impact on the antioxidant activity in black currant, strawberry and white mulberry fruits. Anthocyanins contribute most to the antioxidant activity of chokeberry, blackcurrant, blackberry and cherry fruits, while total phenolics in chokeberry, blackcurrant, blackberry, pomegranate and apple fruits.

In terms of the parameters examined, statistically significant differences were determined between the examined fruit species. A weak positive correlation was determined for total antioxidant activity with vitamin C (0.399) and a moderate positive correlation with total anthocyanins (0.534) and total phenols (0.556), which indicates that in the examined fruit species, antioxidant activity depends more on the content of total anthocyanins and total phenols.

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