Fruits, 2016, vol. 71(4), p. 239–248

DOI: 10.1051/fruits/2016011

FRUITS

Available online at:
www.fruits-journal.org

ORIGINAL ARTICLE

Soluble solids, acidity, phenolic content and antioxidant capacity of fruits and berries cultivated in Serbia

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Received 15 May 2015 – Accepted 7 February 2016

Abstract – Introduction. Cacak is the large fruit production region in Serbia; it presents an enormous diversity represented by different fruit species, highlighting apricot and small fruits. The objective of this work was to investigate and compare the main temperate fruit and berry quality attributes in eight species and their cultivars grown under similar environmental conditions. **Materials and methods.** The species evaluated were blackberry, woodland and domesticated strawberry, red and white currant, jostaberry (*Ribes nigrum* × *Ribes uva-crispa*), gooseberry and apricot. Standard laboratory procedures and methods were used to determine fruit or berry weight, soluble solids content (SSC), acidity (TA) and contents of bioactive compounds. **Results and discussion**. Significant and strong differences among species were detected for all properties evaluated, especially for fruit or berry weight. The fruits of apricot contained the highest soluble solids content (15.28 ° Brix) and ripening index (RI) value (22.49), whereas blackberry is a very rich source of acidity (1.47%), antioxidant power [161.88 mg AA g^{-1} dry weight (DW)], total phenolics (110.07 mg GAE g^{-1} DW) and total flavonoids (51.55 mg RUE g^{-1} DW). A strong relationship between some quality attributes was detected. Also, the cultivar *per se* (genotype) behaved as the most influencing factor determining fruit and/or berry chemical composition. **Conclusion.** Results of our work confirmed that fruits or berries evaluated are rich in primary and secondary metabolites. They showed desirable characteristics for the fresh consumption, while the most of them had high contents of natural antioxidants and may be recommended as a good raw material for the food industry.

Keywords: Serbia / apricot (*Prunus armeniaca*) / *Ribes* spp. / *Fragaria* spp. / flavonoids / nutritional value

Résumé – Acidité, teneur en matières solubles et en composés phénoliques et activité antioxydante de fruits et baies cultivés en Serbie. Introduction. Cacak est la grande région de production de fruits en Serbie ; elle présente une forte diversité illustrée par de nombreuses espèces fruitières, et plus particulièrement l'abricotier et les petits fruits. L'objectif de ce travail était d'étudier et de comparer les principaux attributs de qualité des fruits et baies tempérés de huit espèces fruitières à travers leurs variétés cultivées dans des conditions environnementales similaires. **Matériaux et méthodes.** Les fruits des espèces étudiées sont : la mûre, la fraise domestique et des bois, les cassis rouge et blanc, la casseille (*Ribes nigrum* × *Ribes uva-crispa*), la groseille et l'abricot. Les procédures et les méthodes standard de laboratoire ont été utilisées pour déterminer le poids moyen, la teneur en matières solubles (SSC), l'acidité (TA) et le contenu des composés bioactifs des fruits ou baies. **Résultats et discussion.** Des différences fortes et significatives entre les espèces ont été détectées pour tous les critères étudiés, et particulièrement pour le poids moyen des fruits ou baies. Les fruits de l'abricotier ont présenté la plus haute teneur en matières solubles (15,28 ° Brix) et la plus forte valeur d'indice de maturation (RI = 22,49), tandis que le cassis s'est montré être une source très riche en acidité (1,47%), en pouvoir antioxydant [161,88 mg AA g^{-1} poids sec (DW)], en composés phénoliques totaux (110,07 mg GAE g^{-1} DW) et en flavonoïdes totaux (51,55 mg RUE g^{-1} DW). Une relation forte entre certains attributs de qualité a été détectée. En outre, le cultivar *per se* (génotype) s'est comporté comme le facteur déterminant, le plus capable d'influencer la composition chimique des fruits ou baies. **Conclusion.** Les résultats de notre travail ont confirmé que les fruits ou les baies testés sont riches en métabolites primaires et secondaires. Ils ont montré des caractéristiques souhaitables pour la consommation en frais, puisque la plupart d'entre eux avaient des teneurs élevées en antioxydants naturels, ce qui les rend recommandables comme matière première de qualité pour l'industrie agro-alimentaire.

Mots clés : Serbie / abricot (*Prunus armeniaca*) / *Ribes* spp. / *Fragaria* spp. / flavonoïdes / valeur nutritionnelle

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1 Introduction

Fruit quality is a combination of physical and chemical characteristics accompanied with sensory properties (appearance, texture, taste, and aroma), nutritional values, chemical compounds, mechanical and functional properties [1]. As known, the traditional quality properties in fruits and/or berries are dry matter, sugars, dietary fiber, organic acids and pigments, whereas soluble solids content (consisting mostly of mono- and disaccharides), titratable acidity and juice pH (representative of total acids), contribute to sweetness and acidity of fruits and/or berries and their products [2]. Also, three fundamental components of fruit or berry sensory properties are flavour, sweetness (correlated with soluble solids content), and acidity, whereas firmness contributing to fruit texture and imparting mechanical resistance under transport and handling manipulations is also in demand as it relates to good quality of fresh fruit [3]. Among fruit physical properties, fruit or berry weight, also called "fruit or berry size", is a major quantitative inherited factor determining yield, fruit quality and consumer acceptability [4], and has a direct effect on the marketability and acceptance of fruits and berries in both fresh market and processing [5].

As known, fruit and vegetables are very reach sources of phytochemicals, phyto-nutrients, bioactive compounds and other substances with high antioxidant power [6, 7]. On this line, the consumption of fruits and vegetables plays an important role in the maintenance of health and in disease prevention, such as inflammation, cardiovascular disease, cancer, aging-related disorders, cataract, immune dysfunction, neurodegenerative diseases, etc. [8, 9]. The importance of antioxidant compounds is highlighted by the fact that artificial supplementation of some of these agents might even have harmful effects on the redox homeostasis of the human body [10, 11]. The three most important groups of dietary phenolics are flavonoids, phenolic acids, and polyphenols, flavonoids being the largest group of plant phenols. Phenolic compounds are common in fruit and vegetables, high in antioxidant activity and thought to contribute to the protective effects reported [12]. In addition, phenols contribute substantially to the antioxidant status of many fruit species having potential health benefits [13].

Berries of small fruit species such as blackberries, strawberries, currants, gooseberries, jostaberries, raspberries etc. constitute a good source of natural antioxidant chemicals, and have long been recognized to be especially high in many compounds that have high antioxidant activity and potential to benefit human health [2, 6, 13]. Recently, it has been shown that apricot (*P. armeniaca* L.) fruit provides protection against radiation and have cardio-protective activity that are associated with its antioxident phenolic contents [9]. Besides polyphenolics, apricot is also a rich source of carotenoids and vitamin C [14]. However, there may be considerable variation in chemical composition, *i.e.* bioactive compounds among and within different fruit and berry species. While some species are similar in composition, others differ markedly [3, 12, 15, 16]. Moreover, the chemical composition of fruits and/or berries can be influenced by various factors such as species and genotypic differences, rootstocks, preharvest climatic conditions and cultural practices, location on the tree canopy or bush, maturity and harvesting methods, and postharvest handling procedures [2, 14, 17–19]. From this point, quantification of antioxidant capacity can be achieved in multiple ways and is often confusing to the general public when it comes to determining individual needs and consumption [6].

From above purposes, the aim of this study was to evaluate and compare fruit and/or berry size and basic nutritive value and bioactive compounds content of chosen species and cultivars of blackberry, strawberry [domesticated and woodland], red currant, jostaberry, gooseberry berries and apricot fruit grown under similar environmental conditions. The constituents analyzed were soluble solids content, titratable acidity, soluble solids content/acidity ratio, total phenolics and total flavonoids contents, and total antioxidant capacity.

2 Material and methods

2.1 Study area and plant material

Fruit and berry species involved in this study belong to *Grossulariaceae* (berries), *Prunus* (apricot) or *Rosaceae* (blackberry and strawberry) family. They were grown by authors in their private plantations located in Prislonica village (latitude 43°53' N, longitude 20°21' E, altitude 300−340 m a.s.l.) near Cacak city, Serbia. The plantations were established and managed according to standard cultivation protocols (pruning, fertilization, chemical pest and disease protection, weed control) for intensive production, except irrigation.

The climate in this region is maritime temperate, with moderate to strong winters and hot and semi to dry summers, characterized by the average annual temperature of 11.3 °C and total annual rainfall of 690.2 mm (long-term average). The average air temperature during vegetative cycle was 17.0 °C. Basically, climatic conditions in 2009, 2010 and 2011 were in accordance with long-term average values with small deviation.

The fruits and berries compared in this work were harvested in summer of each two (domesticated and woodland strawberry, white and red currants, jostaberry and gooseberry) or three (blackberry and apricot) year (*table I*) at fully ripening stage on the basis of their skin ground colour, *i.e.* fully coloured, which were suitable for both fresh consumption and industrial use [13, 14]. Immediately after picking, all samples were transferred to the laboratory at Faculty of Agronomy, Cacak where they were kept frozen at −18 °C up to one month until analysis. Prior to the analysis, fruits and berries were defrosted at room temperature. The numbers of cultivars within each species ranged from one (white currant, jostaberry, gooseberry, woodland strawberry) to seven in blackberry.

2.2 Juice extraction and sample preparation

Samples of 40 fruits and/or berries (without stones and seeds) per selected cultivar were gathered, and then divided into 3 subsamples of 5 ripe fruits or berries each. They were

Table I. Family/crop, botanical name, cultivar/genotype and harvesting year of the seven temperate fruit and berry species included in the study.

Family/Crop	Botanical name	Traditional and improved cultivars/genotypes	Harvest year
Rosaceae			
Blackberry	*Rubus fruticosus* L.	Dirksen Thornless, Thornfree, Čačanska Bestrna, Black Satin, Loch Ness, Chester Thornless, Navaho	2009−2011
Strawberry	*Fragaria* × *ananasa* Duch.	Cortina, Selene, Senga Sengana, Marmolada	2010−2011
	Fragaria vesca L.	FA 255/2011[§]	2010−2011
Apricot	*Prunus armeniaca* L.	Harcot, Aleksandar, Biljana, Vera, Roxana, Hungarian Best	2009−2011
Grossulariaceae			
Red currant	*Ribes rubrum* L.	Tatran, Perla, Slovakia	2010−2011
White currant	*Ribes album* L.	Primus	2010−2011
Jostaberry	*Ribes* × *nidigrolaria* R. & A. Bauer	Jostaberry	2010−2011
Gooseberry	*Ribes uva-crispa* L.	May Duke	2010−2011

[§] Improved Serbian selection of woodland strawberry (*Fragaria vesca* L.).

squeezed using a commercial blender. The extracted juices (3 subsamples per cultivar) were later sieved and centrifuged at 15,000 rpm for 20 min (Sigma 3−18 K, Osterode and Harz, Germany).

For determinations of total phenolic content (TPC), total flavonoid content (TFC) and total antioxidant capacity (TAC), fruit and berry extracts were prepared according to AOAC protocols. Briefly, these compounds were extracted from homogenized fruit or berry sample (10 g) using methanol/water (70/30) solvent. Extraction process was carried out using ultrasonic bath Brason B-220 (Smith-Kline Co., Coraopolis, USA) at the room temperature for 1 h. After filtration, 5 mL of liquid extract was used for extraction yield determination. Solvent was removed under vacuum by rotary evaporator Devarot (Elektromedicina, Ljubljana, Slovenia), and was dried at 60 °C to the constant mass. Dry extracts were stored in the glass bottles at 4 °C to prevent oxidative damage until analysis.

2.3 Measurement of fruit weight and determination of soluble solid content and titratable acidity

After harvest, fresh fruits and/or berries (25 per each cultivar per species in four replicates, total 100) were measured for fruit weight. The weight of each individual fruit or berry was recorded with a calibrated electronic balance FCB 6K 0.02B (Kern and Sohn, GmbH, Balingen, Germany), and expressed in fresh weight (g FW).

Soluble solid contents (SSC) were assessed from extracted juice by triplicate with a hand refractometer Milwaukee MR 200 (ATC, Rocky Mount, USA) at 20 °C, and expressed as °Brix. Titratable acidity (TA) was also determined by triplicate using a titration device Metrohm 719S (Titrino, Herisau, Switzerland) with 0.1 N NaOH up to pH 8.1, and results expressed as % malic acid. Once the SSC and TA were assessed, the SSC:TA ratio or ripening index (RI) of the evaluated genotypes was determined. All results were shown as mean values ± standard error (SE) for two or three years (*table I*).

2.4 Determination of phenolics

The TPC, TFC and TAC of fruits or berries of each species and their cultivars were determined spectrophotometrically using UV-Vis spectrophotometer MA 9523-SPEKOL 211 (Iskra, Horjul, Slovenia) with identical methods. All three values are presented as means of triplicate analyses for each cultivar ± SE.

The TPC were estimated according to the Folin-Ciocalteu method [20]. Fruit or berry extracts were diluted to the concentration of 1 mg mL^{-1}, and aliquots of 0.5 mL were mixed with 2.5 mL of Folin-Ciocalteu reagent (previously diluted 10-fold with distilled water) and 2 mL of $NaHCO_3$ (7.5%). After 15 min of staying at the 45 °C the absorbance was measured at 765 nm on spectrophotometer versus blank sample. The TPC was expressed in gallic acid equivalent (GAE) per dry weight [mg GAE g^{-1} DW].

The TFC was determined according to method described by Brighente *et al.* [21]. Briefly, 0.5 mL of 2% aluminium chloride ($AlCl_3$) in methanol was mixed with the same volume of methanol solution of fruit and berry extracts. After 1 h of staying at room temperature (20 °C), the absorbance of the samples was measured at 415 nm on a spectrophotometer versus blank sample. The TFC was expressed as rutin equivalent (RUE) per dry weight (mg RUE g^{-1} DW).

The TAC of the methanol extracts were evaluated by the phosphomolybdenum method [22]. The assay is based on the reduction of Mo (VI) – Mo (V) by the antioxidant compounds and subsequent formation of a green phosphate/Mo (V) complex at acid pH. 0.3 mL of sample extracts were combined with 3 mL of reagent solution (0.6 M sulfuric acid, 28 mM sodium phosphate and 4 mM ammonium molybdate). The tubes containing the reaction solution were incubated at 95 °C for 90 min. Then the absorbance of the solution was measured at 695 nm using spectrophotometer against blank after cooling to room temperature. Methanol (0.3 mL) in the place of extract was used as the blank. Ascorbic acid (AA) was used as standard and the TAC is expressed in mg AA g^{-1} DW.

Table II. Fruit and/or berry fresh weight, soluble solids content, titratable acidity and ripening index of fruit and berry species and their cultivars (means ± SE, n = 100 for FW and n = 3 for SSC, TA and RI, respectively).

Fruit and/or berry crop	Cultivar	Fruit or berry fresh weight (g FW)	Soluble solid content (° Brix) (SSC)	Titratable acidity (TA) (%)	Ripening index (RI)
Blackberry	Dirksen Thornless	5.72 ± 0.29 c	8.28 ± 0.25 d	1.37 ± 0.14 d	6.18 ± 0.38 b
	Thornfree	4.98 ± 0.09 d	8.18 ± 0.08 e	1.66 ± 0.05 b	4.94 ± 0.13 c
	Čačanska Bestrna	7.59 ± 0.01 a	7.11 ± 0.14 f	1.76 ± 0.10 a	4.08 ± 0.24 c
	Black Satin	6.84 ± 0.08 b	6.79 ± 0.02 g	1.49 ± 0.07 c	4.56 ± 0.09 c
	Loch Ness	7.68 ± 0.01 a	9.30 ± 0.01 b	1.49 ± 0.07 c	6.25 ± 0.07 b
	Chester Thornless	5.71 ± 0.10 c	9.23 ± 0.00 c	1.35 ± 0.09 e	6.84 ± 0.09 b
	Navaho	5.64 ± 0.06 c	9.51 ± 0.02 a	1.20 ± 0.15 f	7.99 ± 0.17 a
Average		*6.31 ± 0.40 C*	*8.34 ± 0.41 C*	*1.47 ± 0.07 A*	*5.83 ± 0.52 D*
Cultivated strawberry	Cortina	17.02 ± 1.13 c	10.40 ± 0.43 ab	0.80 ± 0.03 b	13.06 ± 0.57 b
	Selene	21.11 ± 1.19 b	9.80 ± 0.47 b	0.92 ± 0.02 a	10.72 ± 0.67 c
	Senga Sengana	10.46 ± 1.07 d	12.03 ± 0.66 a	0.74 ± 0.01 c	16.26 ± 0.88 a
	Marmolada	27.03 ± 1.57 a	9.70 ± 0.58 b	0.61 ± 0.01 d	15.90 ± 0.79 ab
Woodland strawberry	FA 255/2011	0.59 ± 0.04 e	10.25 ± 0.51 b	0.73 ± 0.03 c	14.04 ± 0.65 b
Average		*15.24 ± 4.55 B*	*10.44 ± 0.42 B*	*0.76 ± 0.05 C*	*14.00 ± 1.01 B*
Red currant	Tatran	0.94 ± 0.06 c	8.50 ± 0.22 c	1.12 ± 0.07 e	7.59 ± 0.34 bc
	Perla	0.82 ± 0.05 d	8.35 ± 0.26 c	1.03 ± 0.05 f	8.11 ± 0.38 b
	Slovakia	0.51 ± 0.04 e	10.65 ± 0.18 b	1.33 ± 0.09 b	8.01 ± 0.35 b
White currant	Primus	0.51 ± 0.04 e	10.65 ± 0.24 b	1.28 ± 0.06 c	11.10 ± 0.44 a
Jostaberry	Jostaberry	1.82 ± 0.07 b	13.10 ± 0.27 a	1.18 ± 0.04 d	11.21 ± 0.49 a
Gooseberry	May Duke	2.83 ± 0.10 a	12.11 ± 0.49 ab	1.94 ± 0.07 a	6.24 ± 0.61 c
Average		*1.24 ± 0.37 D*	*10.56 ± 0.77 B*	*1.31 ± 0.13 B*	*8.71 ± 0.82 C*
Apricot	Harcot	82.46 ± 3.03 b	12.05 ± 0.97 b	0.88 ± 0.01 b	13.69 ± 0.03 d
	Aleksandar	74.02 ± 2.87 d	17.49 ± 0.08 a	0.61 ± 0.04 e	27.80 ± 0.97 b
	Biljana	71.20 ± 2.01 e	16.15 ± 0.19 a	0.71 ± 0.05 c	24.52 ± 1.23 c
	Vera	79.46 ± 3.02 c	16.16 ± 0.20 a	0.53 ± 0.03 f	31.57 ± 1.57 a
	Roxana	99.25 ± 4.43 a	12.92 ± 0.19 b	1.12 ± 0.13 a	11.73 ± 1.00 d
	Hungarian Best	46.94 ± 1.52 f	16.91 ± 1.01 a	0.66 ± 0.04 d	25.62 ± 1.01 c
Average		*75.55 ± 6.99 A*	*15.28 ± 0.91 A*	*0.75 ± 0.09 C*	*22.49 ± 3.25 A*

The different small letter(s) in column indicate significant differences among means within each cultivar at $P \leqslant 0.05$ by the LSD test. The different capital letter in column indicates significant differences among means within each species at $P \leqslant 0.05$ by the LSD test.

The TPC, TFC and TAC values are expressed as means ± SE of triplicate analyses per each species and cultivar for two or three seasons (*table I*).

2.5 Statistical analysis

Statistical analyses were performed using the Microsoft Excel software (Microsoft Corp., Roselle, IL, USA). All data were subjected to basic descriptive statistics, and then evaluated by an analysis of variance (ANOVA) for mean comparisons. Fisher's Least Significant Difference test (LSD) at $P \leqslant 0.05$ was applied for mean values discrimination. Sources of variations were species and cultivars, due to year-by-year variations were not statistically significant.

3 Results and discussion

3.1 Fruit or berry fresh weight

As expected, fruit or berry weight significantly varied across and within species and cultivars (*table II*). Of course, apricot had the highest fruit weight, followed by strawberry. Among species with berries, blackberry had significantly higher weight than species belonging to the *Grossulariaceae* family. Different studies reported that data on the colour, fruit or berry size and weight were not sufficient for consumers. Traditionally, large fruits or berries are preferred by consumers. For example, Hegedûs *et al.* [23] reported that larger fruit is commonly preferred by consumers and apricot markets in recent years. Regarding strawberry, the most desirable are those cultivars that produce large, well-shaped fruit, with bright-red skin colour [24]. For blackberry, large berries are also preferred by consumers, but excessive berry weight (possibly > 15.0 g) is usually not desired for processed or fresh market use [5]. For other berry species, berry weight is in the range previously obtained [25].

Data from *table II* showed large variability among blackberries regarding berry weight. The largest berries had 'Loch Ness' and the lowest 'Thornfree'. These results were higher than those obtained by Eyduran *et al.* [26] and lower than data found by Vrhovsek *et al.* [27] for set of same cultivars. It seems that differences among same cultivars could be due to environmental conditions, growing season and cultural practices. Otherwise, the ideal berry weight for fresh market uses is 8–10 g FW [5].

Among strawberry cultivars, the highest fruit weight produced by 'Marmolada', followed by 'Selene', 'Cortina' and 'Senga Sengana' (*table II*). These findings in the present study were agreed with those reported from literature. So, Radajewska [28] and Milivojević [29] revealed that 'Marmolada' was characterized by large fruits with the highest weight, whereas the smallest fruits were produced by 'Senga Sengana', which confirmed our data. Strong effect of genotype *per se* on this property was previously described [30]. As expected, fruit of *Fragaria vesca* L. (selection 'FA 255/2011') is the smallest than others [31].

For fruit crops belonging to the *Grossulariaceae* family, gooseberry cv. May Duke was found to be highest in berry weight, whereas the smallest berries was observed in red and white currants cvs. Slovakia and Primus, and with no significant difference between them (*table II*). Cultivars of red currants, *i.e.* 'Tatran' and 'Perla' had the largest berries than white currant cv. Primus, which is in agreement with previous study on currant [32]. Similar tendencies among berry crops evaluated for this attribute was previously reported [25].

The apricot cultivars evaluated in this work significantly differed in fruit weight (*table II*). The largest fruits exhibited by 'Roxana' and the lowest by 'Hungarian Best', which is similar with observations in our earlier study [19]. Other cultivars also had large fruits. Many authors worldwide reported high variability among apricots regarding this property. Thus, some authors reported ranges of fruit weight between 36.6 and 105.3 g FW [33] or between 22.9 and 77.5 g FW [23]. Our range of values is in agreement with these results.

3.2 Soluble solids content and acidity level

Significant differences were detected among fruit crops regarding content of soluble solids, acidity and their ratio (*table II*). The highest SSC and SSC:TA ratio (RI) were observed in apricot, and the lowest in blackberry. Strawberries and berry crops belonging to *Grossulariaceae* had similar SSC. The highest TA level was observed in blackberry, whereas the lowest amounts detected in strawberry and apricot, and with no significant differences between them. These findings are in accordance with previous studies which included above enumerated species [2, 25, 33, 34]. In addition, there was a 1.8-, 2.0-fold difference between the highest and lowest SSC and TA respectively, *i.e.* between apricot and blackberry for SSC, and vice versa for TA.

Within species, significant differences were observed among cultivars for SSC, TA and ripening index units (*table II*). For blackberry cultivars, the highest SSC was detected in 'Navaho', and the lowest in 'Black Satin'; the highest RI was also observed in 'Navaho', whereas 'Thornfree', 'Black Satin' and 'Čačanska Bestrna' had the lowest values with no significant differences among them. Large variability among cultivars regarding SSC has been previously observed [35]. Hence, Vrhovsek *et al.* [27] reported that SSC were 9.3, 7.0, 7.5 and 10.6 ° Brix for 'Black Satin', 'Čačanska Bestrna', 'Chester Thornles' and 'Loch Ness', respectively, which confirmed our results in general. Pantelidis *et al.* [13] reported that SSC varied from 9.8 to 11.5%. In addition, Clark and Finn [5] recorded that SSC of at least 10% provides for a "sweet" eating experience for fresh blackberries. The SSC assessment is not only important for juice quality evaluation, but for determining also the suitability of cultivars for blackberry winemaking [36]. Titratable acidity also significantly varied among blackberry cultivars, being higher in 'Čačanska Bestrna', and lower in 'Navaho'. In general, our results are similar to those obtained by Vrhovsek *et al.* [27] for set of same cultivars. Although one acid often dominates, many of the tree fruit and berry species investigated contain a mixture of various organic acids [15]. As known, consumers preferred blackberries with high RI values [37].

Regarding strawberry, 'Senga Sengana' cultivar contained the highest SSC, whereas the smallest was registered in woodland strawberry ('FA 255/2011'), 'Selene' and 'Marmolada' with no significant differences among them (*table II*). Djilas *et al.* [38] also noticed that 'Marmolada' contained lower SSC than 'Clery'. According to data from literature, SSC contents also significantly differed among the strawberry cultivars, ranging from 11.9 to 18.0 ° Brix [16], 5.01 to 7.81 ° Brix [30], 8.0 to 8.8 ° Brix [34], 7.25 to 9.05 ° Brix [38], etc. Most of these interval ranges were lower than SSC values presented in our study, probably due to differences in environmental conditions, farming practices and cultivars evaluated. 'Selene' fruits were found to be richest in acidity content, whereas 'Marmolada' fruits contain the lowest. The quantity of malic acid determined by Skupień and Oszmiański [16] in fully ripe fruit of 'Senga Sengana' was similar to our results. In a study of Wang *et al.* [30] and Djilas *et al.* [38] acidity content significantly differed between cultivars. These authors also reported that, beside others, strawberries with lower fruit weight and acidity, make it an ideal candidate for storage or transportation. Ripening index also significantly varied among cultivars, being higher in fruits of 'Senga Sengana' and lower in 'Selene'. Variability among cultivars has been previously reported by several authors [30, 34].

In fruit crops belonged to *Grossulariaceae* family, the highest values of SSC and SSC:TA ratio were detected in jostaberries, whereas the highest acidity contain berries of gooseberry cv. May Duke. The lowest contents of soluble solids were observed in 'Tatran' and 'Perla', acidity in 'Perla', and SSC:TA ratio in 'May Duke' berries. In previous study on eleven red currant cultivars grown under Serbian conditions, SSC and TA ranged from 9.9 to 12.6% and 1.0 to 1.7%, respectively [39]. In this study 'Slovakia' contain highest SSC and moderate TA levels, which confirmed our results. Moreover, according to Pantelidis *et al.* [13], SSC in berries of four red currant cultivars varied between 7.4 and 10.7%, whereas two gooseberry cultivars contained 8.5% of SSC in average. Skrede *et al.* [2] reported that SSC and TA in berries of gooseberry ranged from 9.0 to 17.1 ° Brix and 1.74 to 3.49%, respectively, whereas in berries of red currants these values are between 8.7 and 15.5 ° Brix, and 1.75 and 3.17%, respectively. Generally, our results are in harmony with data of above authors. The highest value of SSC:TA ratio was detected in jostaberry due to its higher SSC and lower acidity, and the lowest in gooseberry cv. May Duke. From this point, it can be said that red currant, jostaberry and gooseberry juice SSC:TA ratio was basically conditioned by the species and also genotype factor.

Table III. Fruit weight, soluble solid content, titratable acidity and ripening index of evaluated fruit species and their cultivars (means ± SE, $n = 3$). DW: dry weight.

Fruit and/or berry crop	Cultivar	Total phenolic content (mg GAE g^{-1} DW)	Total flavonoid content (mg RUE g^{-1} DW)	Total antioxidant capacity (mg AA g^{-1} DW)
Blackberry	Dirksen Thornless	69.46 ± 1.65 c	33.53 ± 2.51 e	123.80 ± 8.03 e
	Thornfree	63.61 ± 2.16 d	105.10 ± 3.27 a	145.12 ± 14.76 c
	Čačanska Bestrna	111.00 ± 5.01 b	54.63 ± 3.07 c	231.03 ± 7.51 b
	Black Satin	413.20 ± 9.56 a	97.71 ± 1.99 b	312.72 ± 3.04 a
	Loch Ness	45.39 ± 2.52 e	10.24 ± 2.84 f	131.37 ± 3.18 d
	Chester Thornless	34.33 ± 2.22 f	51.98 ± 3.55 d	65.56 ± 2.67 g
	Navaho	33.52 ± 2.13 f	7.69 ± 1.36 g	111.06 ± 4.31 f
Average		*110.07 ± 51.51 A*	*51.55 ± 14.61 A*	*161.88 ± 30.78 A*
Cultivated strawberry	Cortina	35.22 ± 2.45 d	7.21 ± 2.04 e	51.37 ± 0.18 d
	Selene	323.20 ± 9.56 a	93.25 ± 0.99 a	112.72 ± 2.00 b
	Senga Sengana	59.46 ± 1.33 b	53.53 ± 2.01 b	122.80 ± 4.03 a
	Marmolada	47.98 ± 2.11 c	32.88 ± 0.50 c	48.05 ± 0.67 e
Woodland strawberry	FA 255/2011	45.75 ± 1.77 c	12.10 ± 3.00 d	87.12 ± 7.76 c
Average		*102.32 ± 55.26 B*	*39.79 ± 15.66 C*	*84.41 ± 15.30 B*
Red currant	Tatran	75.22 ± 2.00 a	9.27 ± 0.04 c	71.37 ± 0.09 d
	Perla	77.20 ± 0.56 a	11.26 ± 0.09 c	78.72 ± 2.56 b
	Slovakia	79.06 ± 1.56 a	23.53 ± 0.01 b	81.80 ± 0.03 a
White currant	Primus	55.75 ± 1.00 b	32.10 ± 3.56 a	77.12 ± 7.76 bc
Jostaberry	Jostaberry	53.98 ± 2.00 bc	22.00 ± 1.50 b	72.05 ± 0.01 d
Gooseberry	May Duke	48.07 ± 0.07 c	34.00 ± 0.01 a	75.00 ± 0.07 c
Average		*64.88 ± 5.61 C*	*22.03 ± 4.18 D*	*76.01 ± 1.64 C*
Apricot	Harcot	23.78 ± 0.72 a	5.01 ± 0.04 f	13.10 ± 0.18 d
	Aleksandar	13.20 ± 6.56 b	97.71 ± 1.99 a	12.72 ± 0.04 d
	Biljana	12.32 ± 2.21 bc	74.39 ± 3.67 b	17.98 ± 3.54 c
	Vera	9.60 ± 1.05 c	43.53 ± 0.67 c	23.00 ± 0.03 b
	Roxana	3.10 ± 2.06 d	10.10 ± 0.89 e	45.02 ± 4.06 a
	Hungarian Best	12.75 ± 2.13 bc	42.22 ± 1.09 d	16.94 ± 0.77 c
Average		*12.46 ± 2.74 D*	*45.49 ± 14.68 B*	*21.46 ± 4.95 D*

The different small letter(s) in column indicate significant differences among means within each cultivar at $P \leqslant 0.05$ by the LSD test. The different capital letter in column indicates significant differences among means within each species at $P \leqslant 0.05$ by the LSD test.

Since the some evaluated species and their cultivars showed relatively high SSC, they are suitable for both fresh market and juice processing, and all three red currant cultivars and 'May Duke' gooseberry only appropriate for the industry due to its high acidity. Also, the taste and flavour of fruit and/or berries clearly rely on the SSC:TA ratio [30]. Namely, low SSC (consisting mostly of sugars) with high acidity resulted in a tart berry, while low acidity and higher SSC resulted in a blend taste. In cases that both are low, the berries are tasteless.

Fruits of three new Serbian ('Aleksandar', 'Biljana', 'Vera') and old Hungarian ('Hungarian Best') apricot cultivars were found to be richest in SSC and had approximately 1.3- or 1.4-fold the amount of SSC as 'Harcot' and 'Roxana' in average (*table II*). Differences among above four cultivars were not significant, and also between 'Harcot' and 'Roxana'. Likewise, previous studies reported variable ranges of SSC [18, 19, 23, 33]. Regarding acidity content, remarkable differences were found among cultivars, being the highest in 'Roxana', and the lowest in 'Vera'. Wide range of variability among cultivars and growing areas regarding acidity content were found in literature [23, 33], and in their study varied from 0.84 to 2.97% and from 0.91 to 4.39%, respectively. Also, RI values significantly differ. Fruit of 'Vera' had the highest SSC:TA ratio, whereas the lowest was detected in 'Harcot' and 'Roxana'. Since higher SSC:TA ratios correlate well with higher eating quality, these cultivars present a choice of apricots with flavors from sour to sweet and offer the possibility to choose according to consumer and processing preferences [23]. Thus, in the case of some plum, peach, nectarine and apricot cultivars with TA > 0.90% and SSC < 12%, consumer acceptance was controlled by the interaction between TA and SSC rather than SSC alone [4]. However, these authors reported that the establishment of a minimum quality index based on SSC or SSC:TA must be evaluated for each stone fruit cultivar, and also for other fruit species and their cultivars. 'Aleksandar', 'Biljana', 'Vera' and 'Hungarian Best', well known for their good sensorial quality and taste, have been characterized by a balanced sugar/acid ratio as reported by Milošević [unpublished data]. In consumer acceptance studies, these cultivars are often chosen as the most promising fruits.

3.3 Phenolic content and antioxidant capacity

The same types of secondary metabolites were identified in fruit and berries of all evaluated fruit species and their cultivars (*table III*). According to the results, it has been already demonstrated that a wide diversity of TPC and TFC levels and antioxidant capacities exist across and within family and/or species, and among cultivars at same species of evaluated plants.

Quantitatively, berries of blackberry contained the highest TPC and antioxidant capacity among the species, followed by strawberry and species belonging to *Grossulariaceae* family. The lowest contents of total phenolics and TAC were found for apricot, and there were 8.8- and 7.5-fold differences between the highest and the lowest TPC levels and TAC values between blackberry and apricot, respectively. Previous study on apricot indicated that origin play an important role in TPC levels [33]. Most of authors reported that berries of blackberry and fruits of strawberry are a good source of TPC and exhibit high antioxidant activity [3, 16, 30, 34, 40], whereas red currants contained much lower amounts than that of above two species [13]. For example, Guerrero *et al.* [41] noticed that woodland strawberry had higher TPC and antioxidant activity than cultivated strawberry. These findings and our results are in agreement. For gooseberry, our observations are similar to the data obtained by Skrede *et al.* [2], and Pantelidis *et al.* [13], who all reported that berries of this species have higher levels of phenols than red currants. Although apricot contained lower amounts of total phenols than other species evaluated, interest of consumers on fruit health benefits due to its antioxidant profile has recently been raised [9, 18, 42].

Similarly to TPC, blackberry contained significantly higher amount of total flavonoids than other species (*table III*), which is in agreement with previous results [13]. Rich source of TFC in our study are fruits of apricot, followed by strawberry, whereas the lowest amount of this phytochemical was found in red and white currants, gooseberry and jostaberry, respectively. The content of total flavonoids was 2.3- and 2.1-fold higher in blackberry and apricot, respectively, than in species belonging to *Grossulariaceae* family. Similar tendencies for these species were previously reported [3, 42]. In addition, fruits of strawberry contained intermediate amounts of total flavonoids when compared with above enumerated species, although their fruits are important source of this substance [30, 34]. In the literature, there is a great divergence over flavonoids content in fruits and berries indicating a profound influence of cultivar factors, geographical and climate conditions, and analytical procedures employed [3, 14]. However, the growing sites for the fruit species and their cultivars were only a short distance apart and the differences in climate conditions between locations were considered to be minor. According to Remberg *et al.* [43], weather conditions are well known to affect chemical composition of fruits and/or berries. The differences between the three harvesting years appeared to be small in the present study.

A significant difference was found in TPC, TFC and TAC among cultivars of the same species (*table III*). These results could be explained by the high variability of substances with antioxidant characteristics present in the fruits and/or berries.

Regarding blackberries, 'Black Satin' has been shown to be impressive rich source of TPC with the highest antioxidant activity, whereas 'Thornfree' has the highest levels of flavonoids (*table III*). Contrary, 'Chester Thornless' contained the lowest levels of TPC and TAC, and 'Navaho' also had the lowest TPC and TFC values, which is agreed with previous results [44]. Strong impact of genotype *per se* on bioactive compounds in blackberries, and also high discrepancy among results for same or different cultivars were previously reported by other authors [3, 13, 35] as a results of many factors such as stage of maturity, farming practices, weather conditions, different extraction and laboratory methods employed, and tissue type (whole fruit *vs.* puree or juice extract) [44].

In strawberries, the TPC, TFC and TAC of fruits differed strongly across genotypes (*table III*), which is in agreement with previous study on same species [16, 30]. The highest levels of TPC and TFC were found in 'Selene', and the lowest in 'Cortina'. There were 9.2- and 12.9-fold differences, respectively, between the highest and the lowest phenolics and flavonoids level, *i.e.* between 'Selene' and 'Cortina'. In a study of Skupień and Oszmiański [16], 'Senga Sengana' fruits showed 2-3 times lower flavonoids content than other cultivars, which partially confirmed our results. In addition, Djilas *et al.* [38] reported that 'Marmolada' contained higher levels of phenolics and flavonodis than 'Clery' grown under Serbian conditions. Interestingly, 'Senga Sengana' fruits showed very high antioxidant activity, whereas the lowest was found in 'Marmolada', and there was 2.5-fold difference between the highest and the lowest TAC level, *i.e.* between 'Senga Sengana' and 'Marmolada'. Great differences among cultivars regarding antioxidant activity were previously reported [34, 40]. Furthermore, the our results are interesting because previous works do not indicate such relevant differences among cultivars and are even more remarkable if one considers that the strawberry plants in our study have all been grown in the same experimental field under the same environmental conditions and cultural practices.

In the present study all three red currant cultivars contained similar and significantly higher TPC levels than white currant cv. Primus and jostaberry (*table III*); the lowest TPC value was observed in gooseberry cv. May Duke, which is in accordance with previous study on berries [2, 45]. It seems that all three red cultivars had similar phenolic profiles, because their origin is similar [32]. Pantelidis *et al.* [13] also reported that red currants are better source of phenol content than white currants cultivar, whereas, contrary to our results, red and yellow gooseberry cultivars in their study contained higher phenol levels when compared with red and white currants. The differences between our results and those of Pantelidis *et al.* [13] could be explained by differences in the cultivars studied and in the differences of the environmental conditions and cultural practices applied, because the presence of phenolic metabolites in plants is greatly influenced by environmental conditions, and is also genetically controlled [46]. Moreover, Moyer *et al.* [25] reported that gooseberry cv. Captivator had about 1.5 times lower content of total phenolics that six jostaberry genotypes, which confirmed our results. In addition, Wu *et al.* [45] concluded that six cultivars of gooseberry and red currant contained similar TPC levels.

Regarding TFC, the highest values were observed in gooseberry cv. May Duke and white currant cv. Primus, whereas the lowest levels were found in red currant berries cvs. Tatran and Perla, respectively. These findings are in a good harmony with results obtained by Pantelidis *et al.* [13] who

Table IV. Correlation matrix among the studied variables. FW: fruit fresh weight; SSC: soluble solid content; TA: titratable acidity; RI: ripening index; TPC: total phenolic content; TFC: total flavonoids content; TAC: total antioxidant capacity.

Variable	FW	SSC	TA	RI	TPC	TFC	TAC
FW	1	0.699	−0.454	0.828*	−0.439	0.496	−0.588
SSC		1	−0.181	0.694	−0.762*	0.108	−0.824*
TA			1	−0.785*	0.090	0.107	0.361
RI				1	−0.527	0.136	−0.716*
TPC					1	0.333	0.753*
TFC						1	0.207
TAC							1

Asterisk indicate significant correlations among variables at $P = 0.05$.

reported that red currant cultivars contained smaller amounts of total phenolics when compared with other small fruits, whereas gooseberry contained higher levels than red currants. The highest antioxidant activity (TAC) within genotypes belonging to *Grosulariaceae* family was observed in red currant cv. Slovakia, and the lowest in jostaberry and red currant cv. Tatran. Moreover, Wu *et al.* [45] reported that antioxidant power of berries of six gooseberry cultivars and one red currant was quite similar in average. Similar tendencies were observed by Pantelidis *et al.* [13]. The differences between our results and those of Wu *et al.* [45] and Pantelidis *et al.* [13] could be explained by differences in the cultivars used, environmental conditions and cultural practices. However, when comparing quality parameters between different studies it is crucial that differences in methodology are reduced to a minimum.

The great variability was found between apricot cultivars regarding TPC, TFC and TAC levels (*table III*). The highest amount of total phenolics was detected in 'Harcot', and the lowest in 'Roxana'. Contrary, 'Harcot' contained significantly lower total flavonoids, whereas the highest levels of TFC observed in 'Aleksandar'. 'Harcot' and 'Aleksandar' exhibited the lowest antioxidant power, whereas the highest value observed in 'Roxana'. This is in accordance with the reports of Drogoudi *et al.* [33], Kalyoncu *et al.* [9], Schmitzer *et al.* [47], Hegedüs *et al.* [14] and Leccese *et al.* [18, 42] who also reported a large variation of total phenolic and flavonoid content and antioxidant activity for apricot cultivars due to their geographical origin. Additionally, total phenolic content seems to be a good indicator of the antioxidant potential in fruit and authors report correlation between these parameters in different fruit species, including apricot [45, 47].

3.4 Correlations among variables

Relationships among variables evaluated were presented in *table IV*. The fruit weight positively correlated with RI, and negatively with antioxidant capacity, indicated that largest fruits and/or berries increased RI, and decreased antioxidant capacity. Thus, it seems that largest fruits or berries with high SSC:TA ratio level increase sugars content in general, and sweet eating experience [5], but reduced antioxidant power. The correlations between fruit or berry weight and TPC or TFC were not significant. This is in accordance with results from other study [25]. For example, these authors reported that correlation between berry size and TPC in black currants was not found. As expected, SSC *vs.* TA negatively correlated, demonstrating the typical physico-chemical changes with acid converting to sugar in fruits or berries during ripening [45], although relationship between these traits was not significant [48]. Also, a positive correlation was found for SSC and RI, but this relationship was not significant probably due to diverse of species involving in the present study [45].

The significant negative correlations were observed for SSC *vs.* TPC or TAC. These data revealed that fruits or berries which contained high sugar levels had low phenolic content and also small antioxidant activity [37]. As expected, TA negatively correlated with SSC:TA ratio, indicating a decrease in ripening index and sweetness in parallel to increase in acidity. In addition, a weak positive correlations was found between TA and TPC, TFC or TAC, although the content of organic and phenolic acids in berries is responsible for the titratable acidity and is commonly measured as an overall index of fruit quality [17]. Similarly to relation of SSC *vs.* TAC, the correlation between RI and antioxidant activity was significant and negative.

The TPC significantly correlated with TAC, while not correlated with TFC, suggesting that phenols have a more significant contribution to the total antioxidant capacity in apricots [33] and in berries [45]. According to data from relevant literature, levels of total flavonol and total phenolic content also did not correlate, which is not surprising considering that total flavonols accounted for only 2.4−4.0% of the total soluble phenolics in the blackberries [49]. The strong correlation between TPC and TAC confirmed that phenolic compounds are the major sources of antioxidants in the most of fruit and berry species [23,25,30,41,47]. These correlations may reveal a protective effect of pigments not only for human health [50] but also for plant protection against bioagressors, excessive light and also have an important role in attracting pollinating insects [51] or during storage [52] shall be highlighted as well. However, it is important to remember that these correlations were obtained within a diverse group of fruit and berry species. One should be cautious in attempting to extend the conclusion to identical groups of samples, *i.e.* species [45].

4 Conclusion

The wide variation in the fruit and/or berry size and contents of primary and secondary metabolites among different species and their cultivars were found. Among species, apricots had the highest soluble solids content and ripening index value, whereas blackberries had the highest acidity, total phenolic and total flavonoid contents with the highest antioxidant power. Beside species, the cultivar *per se* also behaved as the most influencing factor determining fruit and/or berry size and chemical composition, *i.e.* antioxidant activity. Generally, traditional genotypes such as 'Black Satin' and 'Thornfree' (blackberry), 'Selene' and 'Senga Sengana' (strawberry), 'Slovakia' (red currant), 'May Duke' (gooseberry), and 'Harcot', 'Aleksandar' and 'Roxana' (apricot) can be highlighted due to their higher contents of bioactive compounds. A strong correlations among some variables were found, suggested that pigment-rich fruits or berries have better antioxidant activity. Finally, fruits or berries evaluated showed desirable characteristics for the fresh consumption, while the some of them may be recommended as excellent raw material for the food industry. Also, the combined physical and chemical features can be proposed as good tools for breeders worldwide to improve traditional and select new genotypes, especially with dark colored and larger fruits and/or berries.

Acknowledgements. This work is part of the 31064 Project financially supported by the Ministry of Education, Science and Technological Development of the Republic of Serbia.

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Cite this article as: Tomo Milošević, Nebojša Milošević, Jelena Mladenović. Soluble solids, acidity, phenolic content and antioxidant capacity of fruits and berries cultivated in Serbia. *Fruits* 71(4) (2016) 239–248.